PIBS. 4579e

Compilation of an Ontario Gridded Carbon Dioxide and Nitrous Oxide Emission Inventory

A Final Report to:

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Report No. P-91-50-6436/OG
MOE Reference No.: 203603

September 12, 1991

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Summary

Forecasts of potential climate changes resulting from increases in atmospheric concentrations of "greenhouse gases" are generating widespread scientific concern. In order to study this important environmental issue, define trends and provide data for emission control strategy decisions, various government agencies are compiling emission inventories of the contributing greenhouse gas sources. As part of the Ontario Ministry of the Environment research program, a spatially resolved emission inventory of carbon dioxide and nitrous oxide in Ontario has been developed in this study that can be readily updated.

The Ontario CO_2 and N_2O gridded inventory was prepared for the base year 1988, using methodologies developed by Environment Canada and the Ontario Ministry of Energy, specific data compiled by the Ontario Ministry of the Environment, and other information sources. Although the base year 1988 was selected, the most complete point source information was available for 1987 and, thus, emissions were compiled as a combination of these years. Emission factors were applied to available point and area source base quantity data for each contributing process, in order to compile anthropogenic CO_2 emissions by sector and process at the provincial level. In some instances, previously-developed emission factors were refined or verified by available source test data, some new sources were added and some specific natural source emissions were estimated and included in the inventory. Emissions attributable to various public service sectors and specific industrial source fuel contributions were derived and specified at the provincial level, in order to indicate relative source contributions and provide comparisons with other data. Similarly, major anthropogenic and natural source N_2O emissions were estimated for the same base years using best available reported emission factors. Due to the general lack of measurement and emissions factor data, the emission calculations for nitrous oxide must be regarded as preliminary, first-cut estimates.

Geographical apportioning algorithms, which have been developed in earlier studies along with newly-developed factors where necessary, were applied in order to spatially allocate base quantities by source type and the associated emissions to the variably-sized Ontario UTM grid. After enhancing the database system, all pertinent inventory information was arranged in PC Focus database files, documentation was prepared to facilitate emission reporting and updating, and the

gridded inventory for these species was computed. The following study report indicates the methods used and presents the inventory results.

A summary of the emission totals by general source category with point and area source distributions, is provided in Table 1. The total Ontario carbon dioxide emissions were estimated to be approximately 219 million tonnes of CO_2. This includes the major anthropogenic sources and some directly contributing natural sources, but excludes major natural sources such as plant photosynthesis and decaying organic matter that maintain the carbon budget. As can be seen, fuel and other combustion sources, that represent a portion of the emissions within each general category, account for most of the emissions. Non-energy use, which includes contributions from mineral processing and sectors within the open source category, accounts for a much smaller fraction. Approximately one-half of the total provincial CO_2 emissions have been accounted by point sources. The estimated nitrous oxide emissions, amounting to approximately 54 thousand tonnes of N_2O, are much less certain, especially the contribution by industrial processes and the overall uncertainties associated with N_2O measurements for many of the combustion sources. The geographical distribution of the emissions on the UTM grid in Ontario is shown in Figures 1 and 2. Most emissions occur in the urbanized areas of Southern Ontario, shown in more detail in Figures 3 and 4.

TABLE 1

Summary of Ontario Point and Area Source Emission Totals and Contributions

			CO_2 Emissions (10^6 Tonnes)	(%)	N_2O Emissions (10^6 kg)	(%)
Industrial Processes	-	Point	22.35	(10.2)	13.20	(24.3)*
Stationary Fuel Comb.	-	Point	81.27	(37.1)*	5.38	(9.9)
	-	Area	31.66	(14.5)	0.89	(1.6)
Transportation	-	Area	41.28	(18.9)	15.58	(28.7)
Incineration	-	Point	0.43	(0.2)	0.08	(0.1)
	-	Area	2.86	(1.3)	0.33	(0.6)
Open Sources	-	Area	39.03	(17.8)	18.85	(34.7)
Total Point			104.05	(47.5)	18.66	(34.36)
Total Area			114.85	(52.5)	35.65	(65.64)
Overall Total			**218.9**	**(100)**	**54.3**	**(100)**

* Uncertainties exist for the industrial fuel combustion point source contribution of CO_2 emissions and significant uncertainties exist for the industrial process emissions of N_2O.

FIGURE 1
Ontario Gridded CO_2 Emission Map

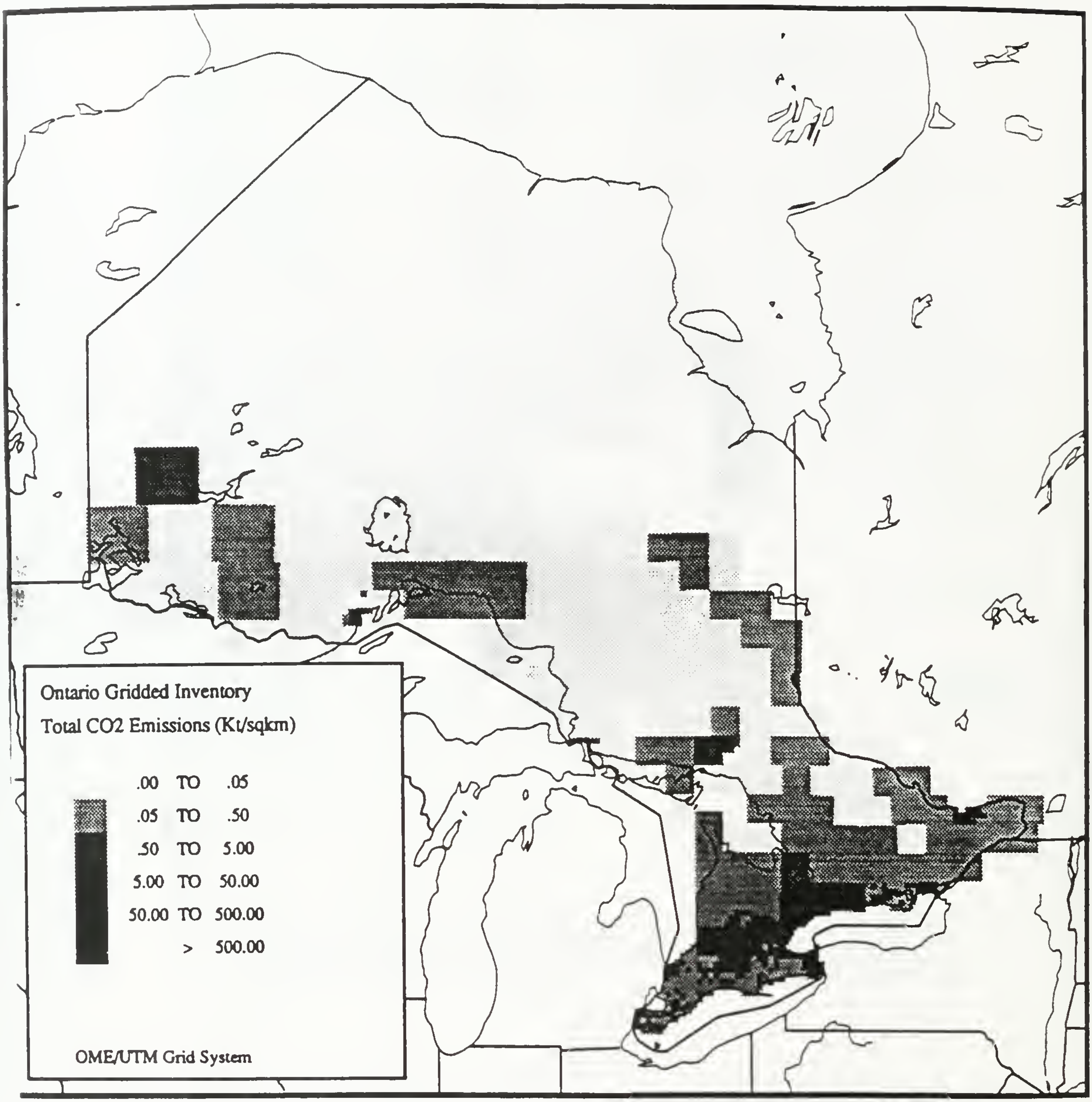

FIGURE 2

Ontario Gridded N_2O Emission Map

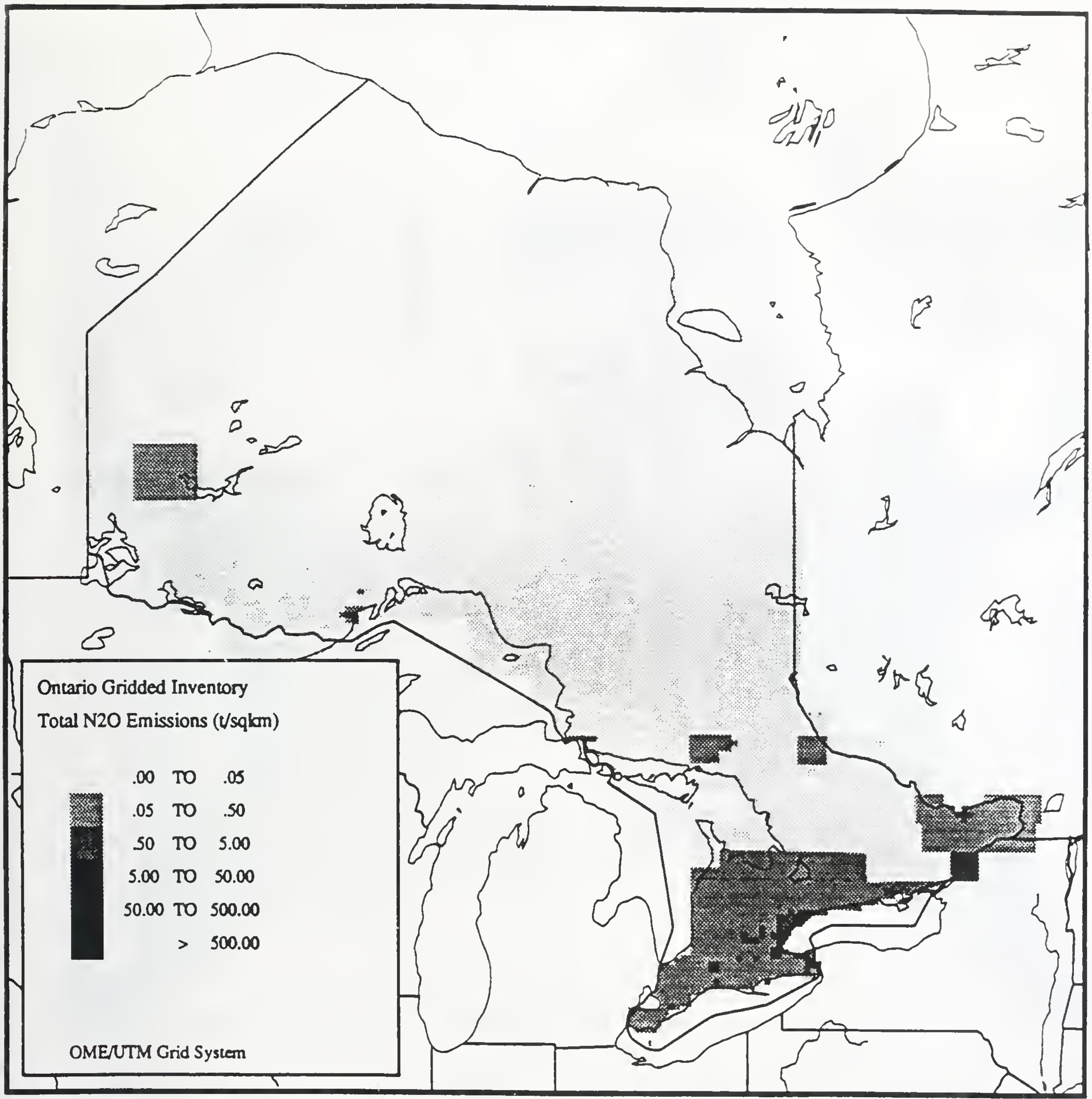

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FIGURE 3
Southern Ontario Gridded CO_2 Emission Map

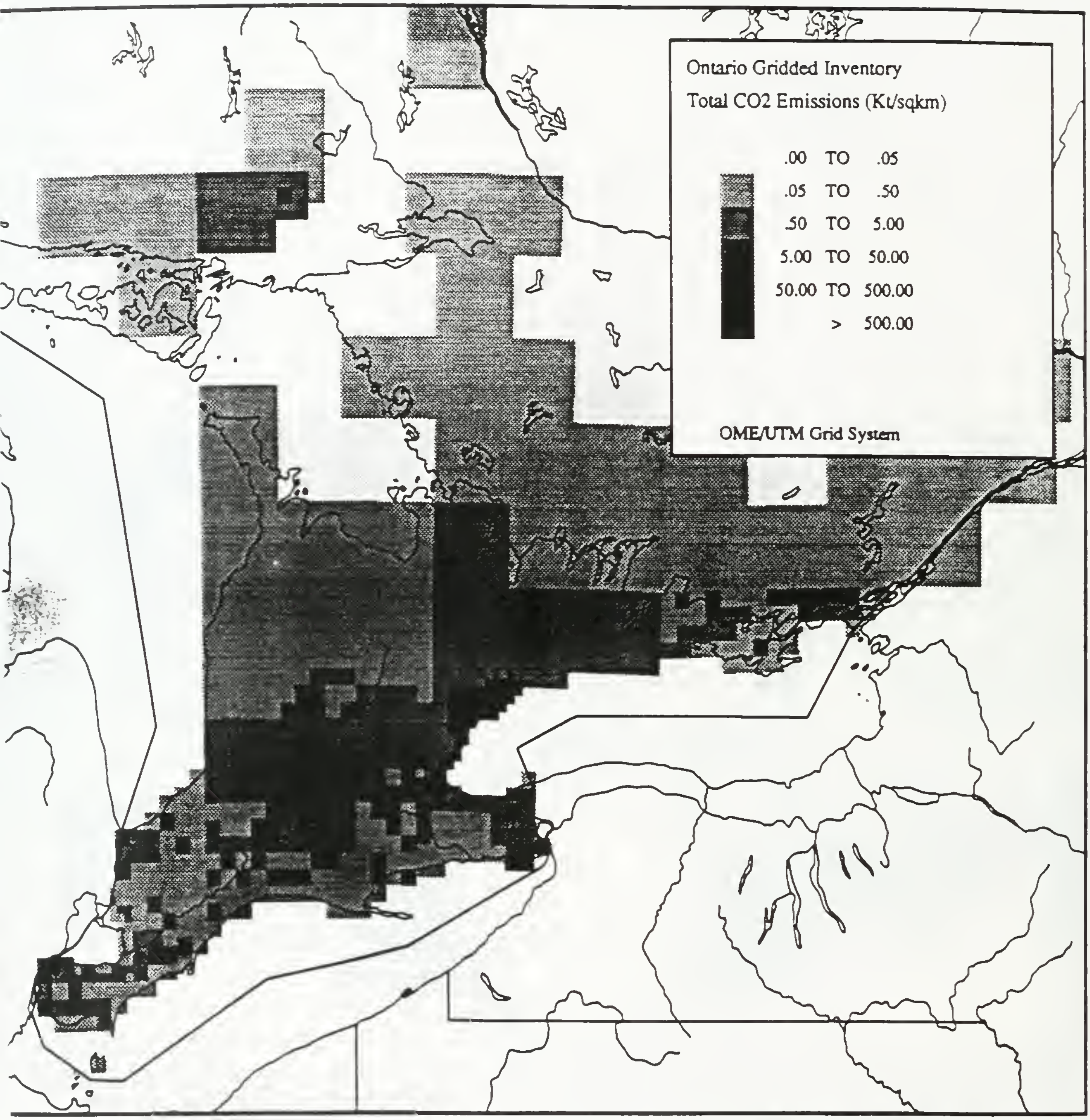
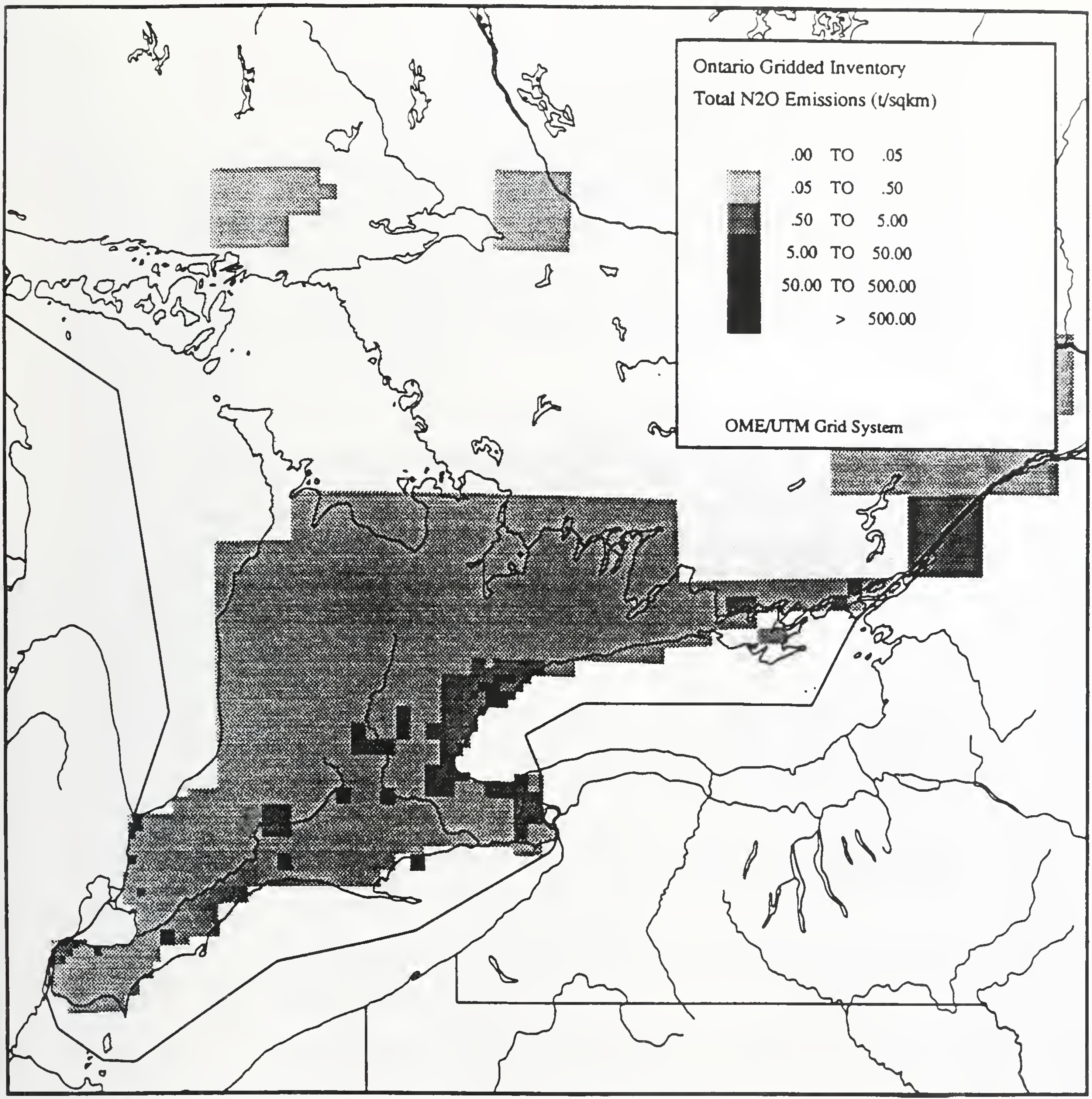


FIGURE 4
Southern Ontario Gridded N_2O Emission Map



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1. Introduction

There is concern that global energy consumption and other human activities are causing the release of excess amounts of "greenhouse" gases that might alter natural balances and affect global climatic conditions. Particular concern is related to atmospheric concentration increases of the following identified greenhouse gases: carbon dioxide, methane, nitrous oxide, low-level ozone, chlorofluorocarbons and water vapour. These allow penetration of most solar energy to the earth's surface, but combine to retard and trap the upward flow of infrared radiation that results in atmospheric heating. Although major uncertainties exist, should current trends continue, alterations in global weather patterns and heat distributions are predicted which could severely affect agricultural and water resources, along with numerous other ecological consequences. Hence, there is need for concerted international efforts to address these issues.

In this respect, the Air Resources Branch of the Ontario Ministry of the Environment has initiated research programs to study the important greenhouse gases. In this study, a database has been established for emissions of carbon dioxide and nitrous oxide in Ontario. The major purposes of this inventory were to define spatial distributions of these species for the initial base year, to allow monitoring of any potential emissions increases in future years and to provide data for model simulations to assist in pollutant control strategy decisions.

The major objectives of the current study were:

- to establish a gridded Ontario CO_2 Emission Inventory for 1988 of all major contributing processes, by adopting the methodologies developed by Environment Canada and the Ontario Ministry of Energy for anthropogenic sources, with refinements where necessary, and developing or incorporating gridded natural CO_2 emission source data,
- to compile the CO_2 and N_2O emissions resulting from the fuel combustion processes in the Ontario Public Service Sectors and various industrial sector fuel contributions at the provincial level,
- to compile a first-cut anthropogenic and natural emission inventory of N_2O and database for the Province of Ontario and allocate emission information into the corresponding UTM grid,
- to prepare these data for use in the existing MOE PC Focus database with provisions to facilitate emission updating.

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2. Background

2.1 Greenhouse Gases

A significant amount of attention is being directed toward the complex issue of global warming and potential effects (Hare 1986a and b, Bernabo 1989, Smil 1989, Environment Canada 1986, Palutikof et al 1984, Singer 1990, Kickert and Krupa 1990). The relative contribution of greenhouse gases, based upon model simulations of radiative forcing due to concentration changes over time, have been reported (Lashof and Ahuja 1990, Rodhe 1990) as noted below:

Species	Estimated Relative Contribution (%)
CO_2	60
CH_4	15
N_2O	5
O_3	8
CFC-11	4
CFC-12	8

2.2 Sources of CO_2 and N_2O

On the basis of available emissions information, the primary anthropogenic sources of CO_2 are fossil fuel combustion, including both stationary and mobile sources, and other industrial processes such as cement production and deforestation. A global CO_2 emission rate of 5.5 GT has been estimated for 1986 from the CDIAC database (Boden et al 1988). In comparison with natural CO_2 emissions (gross primary emissions), anthropogenic sources are estimated to contribute only a small fraction of the total (~2%) (Sullivan 1990). Deforestation, land use and subsequent soil oxidation are estimated to account for one-third of man-made CO_2 emissions. The primary natural sources include: respiration by plants and animals, decaying organic matter, volcanos, forest/grass fires and oceans (Environment Canada 1986). However, on a net basis, natural carbon balancing processes such as photosynthesis and the oceanic reservoir remove most airborne CO_2, and it has been suggested that global man-made contributions are comparable with net natural emissions (Hirschler 1981). In urban areas, predominant anthropogenic emissions would be expected.

At present, it has been estimated that approximately 1/3 of the global nitrous oxide is of human origin, resulting primarily from the application of nitrogenous fertilizers and the combustion of fossil fuels and wood (Environment Canada 1986, Eichner 1990). Soil and water denitrification under anaerobic conditions is the primary natural source of N_2O which is readily taken up by plants. Investigators have questioned recent estimates that suggest global N_2O source emissions exceed the sink capacity by ~30%, and that most of this excess can be attributed to fossil fuel combustion (Kramlich et al 1989). As noted, the relative contribution of anthropogenic N_2O sources, especially fuel combustion, must be regarded as highly uncertain. For example, earlier N_2O emission measurements directly in the flue gases of several U.S. coal and oil-fired thermal generating stations indicated substantial concentrations (i.e., up to 200 ppm). More recently, concentrations of <5 ppm N_2O have been reported in flue gases of utility boilers and, as a result, a much smaller overall contribution is attributable to such sources (Linak et al 1989, Sloan and Laird 1990). Errors in the earlier data were reportedly caused by measurement artifacts (Muzio et al 1989, Lyon et al 1989, Kramlich et al 1989, Sloan and Laird 1990). Despite this, significant concentrations have been found in fluidized bed coal-fired boilers (Kramlich et al 1989, Aamand and Anderson 1989). Nitrous oxide is known to be emitted in catalyzed vehicle exhausts, based upon EPA test procedures (Smith et al 1980). In addition, it has been estimated that ~2500 T/yr N_2O releases occur in Germany as a result of its anaesthetic use (Mueller 1985). Of particular importance, fertilizer-derived N_2O emissions data have recently been consolidated from soil science literature (Eichner 1990). Biomass burning tests in Ontario, with focus on N_2O emissions, have also been done (Donaldson 1988).

Nevertheless, it is generally recognized that nitrous oxide emission inventory data are more limited than carbon dioxide data.

Both Canadian and Ontario carbon dioxide emission inventories for anthropogenic sources have been compiled which indicate the magnitude and source contributions at the provincial level (Environment Canada 1989, Ontario Ministry of Energy 1990). The Ontario inventory was compiled for specific fossil fuel and wood combustion sources for the base year 1988 and projected to the year 2000; whereas the Canadian inventory addressed essentially all major sources including CO_2 released during cement production and other industrial process emissions for the year 1987. Despite some differences between sector totals and specific assignments, the overall total emissions and source category contributions were generally similar.

3. Methodology

3.1 General

As noted in the Introduction of this report, some of the major objectives of this inventory were:

- to refine and supplement previous CO_2 inventories and develop an N_2O inventory for Ontario, and subsequently grid these inventory data on the UTM grid system,

- to provide detailed breakdowns of industrial and commercial/institutional fuel combustion emissions of CO_2 and N_2O for sectors used in other energy assessments,

- to prepare this data for use in the existing MOE PC Focus database with provisions to facilitate emission updating.

However, in designing the inventory methodology it became apparent that the first two objectives were not consistent with the third, for a number of reasons. The most important objective in the study design was that the inventory be as compatible as possible with other MOE inventories (criteria pollutant and toxic) and that this inventory be updateable. This put a number of constraints on inventory design:

- rather than gridding previously reported emissions (as in the first objective listed above), base quantities would be gridded and used in conjunction with emission factors to create a gridded inventory. In this manner, the inventory can be updated to reflect either revised base quantities or new emission data,

- the current MOE point and area source system would be used, with new sectors (not currently inventoried for criteria pollutants) to be added in consultation with the MOE. Accordingly, some currently available CO_2 emission factors (from Environment Canada studies) had to be revised to be compatible with the MOE sector designations and base quantity units.

- a detailed breakdown of industrial and commercial/institutional fuel combustion emissions would not be compatible with the current MOE inventory system. Therefore, this breakdown was done using information from the system on a provincial total basis outside of the updateable inventory.

Other key features of the CO_2/N_2O inventory are as follows:

- a base year of 1988 was chosen. However, 1988 point source files for Ontario were not available. Therefore, point source files for 1987 and area source files for 1988 were used,

- energy related emissions are based on a fuel use basis (in order to be compatible with the current MOE system).

The remainder of this chapter provides an overview of the methodologies used in this CO_2 and N_2O inventory.

3.2 Overview of Emission Factor Derivations by Source Category

Anthropogenic emissions of CO_2 and N_2O are primarily associated with combustion of various fuels. Specific industrial processes also release emissions of these gases (e.g., the decomposition of inorganic carbonates to yield CO_2) and certain natural sources are important in the generation of CO_2 and N_2O (e.g., animal respiration and fertilized soil nitrification, respectively). In the compilation of this inventory, the major source categories in Ontario have been addressed that release primary emissions of these gases while other major natural sources/sinks that maintain global carbon and nitrogen balances (e.g., vegetation, soil biogenic emanations) have not been included. The major source categories (with corresponding sector and process contributions) are:

Industrial Processes
Stationary Fuel Combustion
Transportation
Incineration
Miscellaneous and Open Sources

In most instances, emission factors reported by Environment Canada have been used to derive carbon dioxide emissions at the process level for each major source (Jaques 1990). The reported emission factors were determined on a carbon mass balance basis with amount of the carbon content of the particular fuel or raw material and the fraction of the fuel oxidized (i.e., the estimated portion of hydrocarbons and particulate matter formed during combustion that prevent complete oxidation of the fuel carbon to carbon dioxide) or fraction of the raw material consumed in the process. The emission factors include CO with the assumption that CO oxidizes to CO_2 in the atmosphere within weeks (Jaques 1990). In all cases, the emission factors that were reported in units of g carbon per mass or volume of fuel or t carbon/terajoule were converted to tonnes carbon dioxide per mass or volume of fuel, in order to be consistent with available base quantity data in the MOE inventory. In some cases, other data were used to derive or verify the CO_2 emission factors (e.g., source measurements and information reported in various publications and reports).

Similarly, in most instances, N_2O emission factors reported by Environment Canada based on measurements were used in this study (Jaques 1991). It should be noted that the mechanisms of N_2O formation during combustion are not well understood and the limited number of emission factors that have been reported are uncertain. Although source data are available to relate NO_x emissions to N_2O in the presence of reactants such as SO_2, based on empirical or modelled relationships (Muzio et al 1989, Lyon et al 1989, Sloan and Laird 1990), data have yet to be fully substantiated. It should also be noted that the N_2O emission factors used are not associated with a fraction of NO_x components, since discrete measurements are made for this species and conventional measurement techniques for NO_x are not expected to respond to N_2O. However, this latter point requires confirmation. Emission factors for some sources were obtained from other published information and recent source test data were used to derive an emission factor for coal-fired power generation facilities in Ontario. In all cases, emission factors reported as kg N_2O-N/fuel unit were converted to kg N_2O/fuel unit.

Emission factors developed for CO_2 and N_2O were assigned profile numbers and names by sector and/or or fuel type, as appropriate. These profiles are presented in Table 5.1.1, Chapter 5. All point and area source records pertinent to this inventory were assigned default profile numbers (see Table 5.1.2). Where site-specific emission factors were used, site-specific profiles (series 600 in Table 5.1.2) were assigned on a point basis, overriding the default profile assigned.

3.3 Base Quantity Data and Geographical Apportionment

Wherever possible, point and area base quantities were taken from the 1987 point and 1988 area MOE inventory base quantity files. Thus, for point sources, Source Classification Codes (SCCs) are used, and for area sources the MOE Sector Codes (SCs) are used.

A number of revisions and additions were made to the MOE files. (These additions/revisions are flagged in the files as noted in Appendix A). In general, the changes involved:

- the addition of plants for the lime production, incineration and hospital sectors (see Table 3.3.1). In some cases, process-related points were added to existing plants,
- SCC corrections to the incineration sectors,
- base quantity corrections as required,
- infilling of zero base quantities. For points in industrial processes, these were corrected using site-specific information. In other sectors, base quantities were back-calculated from criteria pollutant emissions using AP-42 emission factors.
- A number of new area source sectors were required. These are listed in Table 3.3.2. Details of the base quantity development and geographical apportionment are outlined in the appropriate section in Chapter 4.

Complete descriptions for the SCCs and SCs used in this inventory may be found in Table 5.1.2.

All base quantity and emissions data were geographically apportioned to the variably-sized UTM grid network for Ontario, which had been developed in earlier studies (ORF 1983). Point sources were located within the grid on the basis of known UTM coordinates and area source emissions were allocated on the basis of surrogate apportionment assignments developed previously. The public administration/industrial sector fuel combustion CO_2/N_2O emissions breakdown (on a provincial basis) was based on base quantity and apportioning data from a number of sources:

TABLE 3.3.1

New Plants Added to the MOE Point Source Files

Plant ID	Plant Name	Comment
100622	Beachville	Lime Kiln
200857	Guelph Dolime	Lime Kiln
500165	Reiss Lime	Lime Kiln
500166	Timminco	Lime Kiln
300566	Highland Creek	Sewage Sludge Incinerator
100623	Laidlaw	Industrial Incinerator
303905	GM Canada	Industrial Incinerator
300267	York Central	Hospital Incinerator
301335	Humber Memorial	Hospital Incinerator
301336	Women's College	Hospital Incinerator
301337	Oakville Trafalgar	Hospital Incinerator
100268	Victoria Hospital	Hospital Incinerator
301117	Milton District	Hospital Incinerator

TABLE 3.3.2

Area Source Codes Added to the MOE Area Source Files

SC	Description	Units
93	Fertilizer application	tonnes fertilizer (as N)
139	Pipelines (compressors)	km (of pipeline)
140	Anaesthetic gas usage	population
141	Propellant usage	population
142	Respiration - Humans	population
143	Natural soils - coniferous forest	km^2
144	Natural soils - deciduous forest	km^2
145	Natural soils - swamplands	km^2
146	Natural soils - grasslands	km^2

- point source data from the CO_2/N_2O inventory,
- Statistics Canada base quantity data (Report 57-003),
- the Ontario Ministry of Energy estimated sector/fuel consumption data,
- various statistics relating to employment or floor space data, by sector, for use in apportioning data.

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4. Source Category Inventory Methods

4.1 Industrial Processes

4.1.1 Cement Manufacturing

The production of cement represents a source of atmospheric carbon dioxide due to both fuel usage in kilns and process CO_2 released from the calcination of calcium carbonate rich materials (e.g., limestone, marl, chalk), together with other materials in the feed. Environment Canada and others have derived an emission factor of 0.50 t CO_2/t cement on the basis of an average of 63.5% calcium oxide content of cement (Jaques 1990, Marland et al 1989). This emission factor was applied to individual cement manufacturing facilities in Ontario to account for the cement processing contribution to the emissions (i.e., excluding fuel combustion contributions).

An examination of available source test data for selected cement manufacturing plants in Ontario has been used to substantiate this emission factor (ORTECH 1984 and 1988a). For example, an average value of 1.07 t CO_2/t cement produced was obtained from stack measurements at one facility which included the CO_2 contribution from fuel combustion (i.e., coal, solvents, etc.). On the basis of reported fuel consumption information for specific facilities (i.e., approx. 0.16 tonne coal is burned in producing 1 tonne cement), and the reported CO_2 emission factor for Canadian bituminous coal of 2.54 t CO_2/t coal (Jaques 1990), the resulting average emission factor for cement production including the coal combustion contribution, was estimated to be:

$$0.50 + (0.16 \times 2.54) \approx 0.91 \text{ t } CO_2\text{/t cement produced}$$

Because this value is only slightly lower than the average value derived from source test results, these data provided additional confidence in the Environment Canada emission factor applied for the cement manufacturing process. The emission contributions due to fuel combustion at these sources, as discussed in Section 4.2, were also applied on a point source basis, and were included with the industrial fuel combustion sector.

The base quantities (i.e., tonnes of cement produced) for some Ontario cement manufacturing facilities were missing in the Ontario inventory database. The missing data were estimated on the basis of reported capacity information (EMR 1988), and corrections made to other base quantities and point sources as required.

4.1.2 Lime Manufacturing

The production of lime involves calcining limestone at high temperature, usually in a rotary kiln fired by conventional fossil fuels, to drive off carbon dioxide from the carbonate rock. Both high calcium and dolomitic limestone may be processed from the quarried limestone in accordance with the following theoretical calcination reactions:

$$\mathrm{CaCO_3} \xrightarrow{\text{Heat}} \mathrm{CaO + CO_2}$$

$$\mathrm{CaCO_3 \cdot Mg\,CO_3} \xrightarrow{\text{Heat}} \mathrm{CaO.MgO + 2\,CO_2}$$

The carbon dioxide emission factors of 0.79 and 0.92 t CO_2/t quicklime produced, were derived on a mass basis and applied to individual facilities operating in Ontario. The selection of the emission factor was based on the general type of limestone found in the vicinity of each lime producer (i.e., Hewitt and Vos 1972) In instances where the type of limestone processed was uncertain, an average emission factor of 0.85 t CO_2/t quicklime produced was applied to the facility. It can be expected that these CO_2 emission factors may slightly overestimate the actual amount of CO_2 emitted for the following reasons:

- siliceous rock or other impurities in the feed and product will reduce the theoretical amount of CO_2 generated,
- the CO_2 emission will be affected if the product of the facility is reported as hydrated lime rather than quicklime,
- a small portion of CO_2 may be adsorbed on the kiln product to result in somewhat reduced CO_2 emissions.

Actual lime producers and quantities of lime produced in Ontario, based on capacity information, were obtained from Energy, Mines and Resources publications (EMR 1988) and were entered into the inventory database as point sources. For the reasons noted above, the CO_2 emissions for this sector may be somewhat over-estimated, but the extent to which the emission factor should be decreased is presently uncertain. Emissions related to fossil fuel combustion for these facilities were included with the industrial fuel combustion sector.

4.1.3 Kraft Pulp and Paper Manufacturing

Apart from associated fossil fuel combustion emissions at sulphate pulping facilities (inventoried as industrial fuel combustion), other sources of process CO_2 emissions include lime production and black liquor combustion.

Lime is used in the production of kraft pulp to neutralize the process chemicals and is usually produced at the plant. This is classified as captive lime production and is not included in commercial lime production statistics (see Section 4.1.2). CO_2 emissions occur from the calcination reaction in the lime kilns. It has been assumed that only high calcium limestone is calcined to produce quicklime at sulphate pulping facilities and that CO_2 is released by:

$$CaCO_3 \quad \xrightarrow{\text{Heat}} \quad CaO + CO_2$$

On a mass basis, approximately 0.79 tonne CO_2 is emitted per tonne of lime produced. For consistency with available base quantity data in units of pulp produced, the emission factor for lime kilns was estimated using reported production capacity information (Lockwood Directory 1989) for various individual facilities (e.g., approximately 170 tpd calciner for 680 tpd pulp capacity). Thus, the emission factor derived for lime kilns at kraft pulp and paper plants was:

$$0.25\ (0.79) \approx 0.20\ \text{t}\ CO_2 \text{ per tonne pulp produced}$$

This emission factor was applied to all point source facilities in the Ontario inventory database.

Black liquor generated in kraft pulping that contains ~65% solids is burned in recovery furnaces, whereby the solids support combustion and the inorganic salts are recovered for processing. On the basis of the average carbon content and the emission factor reported by Environment Canada (Jaques 1990), emissions were calculated based on the amounts of black liquor burned at each plant.

4.1.4 Coke Production

Metallurgical coke is produced in slotted coke ovens at integrated iron and steel plants, and used primarily in blast furnaces and other high temperature operations at these facilities. Emissions of greenhouse gases can be expected for a variety of processes during production of iron and steel. For example, during the production and use of coke, the amount of CO_2 vented directly from the coke ovens during pyrolysis of coal is highly uncertain, since a portion will be contained in the COG used in other heating processes. Similarly, the amount of CO_2 generated by coke consumption in the blast furnaces, in conjunction with recirculation of the blast furnace gas, is uncertain. However, it is presumed that the emissions from these operations will occur within the same year of the initial coke produced. An emission factor of 2.39t CO_2/t coal used for coke combustion has been derived by Environment Canada, by accounting for an average fraction (i.e., 6%) of coal that results in coke by-products such as light oils and crude tars (Jaques 1990). This emission factor was assigned to coal used in coke ovens at the four primary steel producers in Ontario, and to the beehive coke ovens used at other facilities. Similarly, a coal combustion emission factor of 0.11 kg N_2O/t coal burned was applied (Jaques 1991). Although emissions of these species may not entirely occur during metallurgical coke production, the remaining portion of the emissions might be expected to occur in closely-linked coke combustion processes and the combustion of COG process gas in various operations. Thus, the emissions have been assigned to coking operations, in order to account for the fuel consumed during production of iron and steel. The amount of coal consumed at each facility was contained in MOE inventory point source files with designation to either oven charging or coke quenching operations.

4.1.5 Ammonia Production

Carbon dioxide is emitted from the Haber-Bosh process used to produce ammonia due to the consumption of natural gas as the source of process hydrogen. An emission factor of 1.56 t CO_2/t ammonia produced was derived by Environment Canada for this process (Jaques 1990). Emissions were determined for the one major ammonia producer in Ontario from production data contained within the MOE point source file.

4.1.6 Nitric Acid Production

The production of nitric acid by ammonia oxidation may release emissions of nitrous oxide. However, the release mechanisms and quantities produced are uncertain. As discussed by Environment Canada, N_2O emissions have been estimated for plants producing nitric acid as an intermediate product formed in the manufacture of nitrogen fertilizers (Jaques 1991). An uncontrolled emission factor, related to amounts of nitrogen-containing fertilizer produced, was derived on the basis of Norwegian information. However, this factor has been revised for current Canadian inventories, on the basis of new information received from ICI (United Kingdom) for inventory working groups for global warming issues (Jaques 1991, Personal Communication). The revised emission factor has been further developed for this study (i.e., Ontario data requirements) using the following information.

The essential steps in the nitric acid process (Kirk Othmer 1981) comprise:

Ammonia Oxidation $NH_3 + 1.25\,O_2 \xrightarrow{\text{catalyst}} NO + 1.5\,H_2O$

NO Oxidation $2\,NO + O_2 \rightarrow 2\,NO_2$

NO_x Absorption $3NO_2 + H_2O \rightarrow 2\,HNO_3 + NO$

Under some conditions, a portion of ammonia may be consumed by side reactions or incomplete oxidation of ammonia with partial conversion to N_2O (Wong 1991, Jaques 1991, Personal Communication), according to the following reactions:

$$2\,NH_3 + 1.5\,O_2 \rightarrow N_2 + 3H_2O$$

$$2\,NH_3 + 2\,O_2 \rightarrow N_2O + 3H_2O$$

At Canadian facilities, gases from absorber towers are transferred to a catalytic combustor which are reacted with methane to control emissions of nitrogen oxides. This may limit the release of N_2O. In plants producing ammonium nitrate fertilizers, potential formation of N_2O may also occur due to thermal decomposition of NH_4NO_3. However, process temperatures are normally lower than reported decomposition temperatures and, thus, the possibility of related emissions is not known (Wong 1991, Personal Communication).

A median emission factor of 8.5 kg N_2O/tonne of ammonia consumed for nitric acid production has been derived on the basis of European test data with a range of 2.5-20 kg/t for individual manufacturing facilities (Jaques 1991, Personal Communication). This factor has been applied to Canadian facilities using published ammonia production data for Canada. Since available base quantity data in MOE files for individual plants represent the amount of HNO_3 produced (i.e., rather than the amount of NH_3 consumed), this median emission factor was converted to 3.44 kg N_2O/t HNO_3 produced, on the basis of the above-mentioned reactions and the related balance that one mass unit of NH_3 is consumed to produce 2.36 mass units of HNO_3. Only two nitric acid producers in Ontario were identified in the files for which emissions were estimated. This emission factor was assigned to the SCC 301013XX corresponding to the amount of nitric acid produced at these facilities.

4.1.7 Adipic Acid Production

Nitrous oxide is a by-product in the manufacture of monomers 6,6- and 6,12-nylon. Nylon polymers are typically formed by condensation polymerization of a dicarboxylic acid, most commonly adipic acid, and diamine. Adipic acid is prepared primarily by air oxidation of cyclohexane to cyclohexanol-cyclohexanane mixtures, followed by oxidation with N_2O to adipic acid. Thiemens and Trogler (1991) estimate that approximately 300 kg of N_2O is released for every tonne of adipic acid produced. This is considered to be an upper limit, since the effects of most emission controls on N_2O release is not known. A few companies do treat emissions with a reductive furnace, which destroys N_2O. Globally, this source of N_2O is thought to account for as much as 10 percent of increases in atmospheric N_2O (Thiemens and Trogler 1991).

One producer of adipic acid was identified in the MOE point source file. N_2O emissions were determined using an emission factor of 300 kg/t of adipic acid and assuming no process control at the site.

4.2 Stationary Fuel Combustion

For stationary fuel combustion, emissions of CO_2 and N_2O were largely calculated using CO_2 and N_2O emission factors that were specific to the fuel combusted, rather than the type of fuel combustion facility. For example, emission factors for natural gas combustion are the same for industrial, commercial/institutional and residential sectors. Exceptions to this methodology are discussed in the appropriate section.

CO_2 Emission Factors:

Carbon dioxide is an end product of the combustion or incineration of organic materials, such as coal, petroleum, gas, wood and waste materials. Most CO_2 fuel-based emission factors used in this inventory were based on those developed by Environment Canada for use in a national inventory of CO_2 (Jaques 1990). CO_2 emission factors from fuel combustion in the Environment Canada inventory were expressed as the product of two terms: the carbon content of the fuel and the fraction of the fuel oxidized. No CO_2 control is assumed. This is consistent with a recent review (Piccot et al 1990) which found that CO_2 reduction is negligible for most pollution control technologies (with the exception of CO_2 scrubbing on utilities emissions which is not a commercially proven technology). All emission factors were derived on an energy basis and were converted for use in the Ontario inventory by using conversion factors in the Environment Canada report (see Table 4.2.1). The carbon content and heating values used in this derivation reflect typical Canadian fuel values. Details are available in Jaques 1990. A recent review of CO_2 emission factors (Picot et al 1990) and inventory methodologies compared well with the factors listed in Table 4.2.1.

The following cross-assignments were made when fuel-specific CO_2 emission factors were not available:

Fuel Type	Emission Factor Used
process gases	natural gas
butane	propane
solid waste - not specified	industrial solid waste (see Section 4.3), municipal solid waste (see Section 4.3) or fuel wood, on a point-by-point basis

In addition, there were some SCCs which appeared to be related to fuel combustion but for which the waste type was not specified and so could not be inventoried:

SCC

102999-99
301999-99
302999-99
305999-99
399999-99

Nitrous Oxide Emission Factors

Emissions of nitrous oxide from fuel combustion were also based on an Environment Canada report (Jaques 1991).

Very few valid nitrous oxide emission factors are available, since measurements made before 1988 may have overestimated N_2O emission rates, due to a sampling artifact occurring in stored grab samples containing NO and SO_2 (Jaques 1991). Emission factors (Table 4.2.2) developed by Environment Canada are based on the work of De Soete (1989) and CANMET/CEA work for fossil fuels (1990) and Roslund and Steen (1990).

For fossil fuel combustion, the N_2O emission factors were based on stoichiometric flue gas volumes per unit mass of fuel and typical measured N_2O flue gas concentrations.

For example, emissions of N_2O due to combustion of coal were estimated by Environment Canada using average measured N_2O concentrations in coal-fired boiler emissions and stoichiometric fuel gas volumes generated by a known amount of coal consumption (Jaques 1991). The parameters selected for this calculation were:

Mean N_2O Conc. ≈ 6.2 ppm (Range 3.7-7.8 ppm)
= 11.5 mg/m³ (converted using a molar volume of 23.7 m³ at 1 atm and 60°F)

Flue Gas Volume = 8.54 Nm³/kg coal
and with 10% Excess Air = 9.39 Nm³/kg coal

This volume is generally consistent with values derived from other reported data (U.S. Dept. of Health 1966). The resulting emission factor that can be estimated from this information is:

$0.0115\text{g } N_2O/m^3 \times 9.39\ m^3/\text{kg coal} \quad = \quad 0.11\text{ g } N_2O/\text{kg coal or } 0.11\text{ kg } N_2O/\text{t coal.}$

This emission factor was generally applied to industrial and other coal-burning facilities in this inventory, with the exception of coal-fired utilities (see Section 4.2.1).

Calculations for natural gas, heavy (and light) oil, gasoline and diesel oil were done in a similar manner to coal, using the following parameters (Jaques 1991):

Fuel	Stoichiometric Flue Gas Volume (Nm3/kg)	Density (kg/Nm3)	PPMV
natural gas	10.91	0.78	1-1.5
heavy (and light) oil	9.72	930	1-12
gasolines:	not specified	750	
no catalyst			3-40
new catalysts			2 to 5 times uncontrolled
aged catalysts			~7 times uncontrolled
diesel	not specified	870	3-40

The emission factor of 0.1 kg N_2O/tonne for fuel wood combustion was taken from Roslund and Steen (1990) (as cited by Jaques 1991).

The following cross assignments were made when fuel-specific N_2O emission factors were not available:

Fuel Type	Emission Factor Used
process gases	natural gas
kerosene	light oil
solid waste	fuel wood

A review of the literature identified very little comparable N_2O emission data, and so it is not possible to compare the N_2O emission factors used for the current inventory to other studies.

4.2.1 Electric Power Generation

Utilities are inventoried as point sources in the MOE inventory system. Coal is by far the principal fossil fuel used for electricity generation in Ontario, with over 10 x 10^6 tonnes of bituminous and over 1 x 10^6 tonnes of lignite consumed. Distillate oil is also used in much smaller amounts (38 x 10^3 m^3).

Emissions of CO_2 were calculated using fuel-based emission factors from Table 4.2.1. The N_2O emission factor (Table 4.2.2) used for distillate oil combustion was discussed above.

For coal-fired generating stations, a sector-specific N_2O emission factor was derived from recent source test data at an Ontario Hydro coal-fired generating station (ORTECH 1990). The average flue gas N_2O concentration from a series of tests at 2,400 MW station load was found to be 5.3 ppm, which is consistent with other reported test data. The average N_2O emission rate was determined to be 0.0233 kg/second at this power rating. On the basis of the reported energy content for Canadian bituminous coal of 29.3 GJ/t (Jaques 1990), the coal feed rate was estimated to be 0.0816 tonne/second. Accordingly, the derived emission factor from these test data was 0.29 kg N_2O/t coal. This factor was applied to the individual coal-fired generating stations in Ontario, on the basis of coal consumption for each facility contained in MOE point source files.

No additions or revisions were made to the MOE file.

4.2.2 Industrial Fuel Combustion

Industrial fuel combustion is inventoried for the following categories of point (external combustion boilers and in-process fuel) and area sources in the MOE inventory:

TABLE 4.2.1

Fuel Combustion CO_2 Emission Factors
(Jaques 1990)

Fuel Type	CO_2 Emission Factor (t/TJ)	Gross Energy Content	CO_2 Emission Factor (t/unit)
Gaseous Fuels			
Natural Gas	49.68	38.03 MJ/m^3	.001889 t/m^3
Liquid Fuels			
Motor Gasoline	67.98	34.66 GJ/m3	2.356 t/m^3
Kerosene	67.65	37.68 "	2.549 "
Aviation gasoline	69.37	33.52 "	2.325 "
Propane	59.84	25.53 "	1.528 "
Diesel Oil	70.69	38.68 "	2.734 "
Light Oil	73.11	38.68 "	2.828 "
Heavy Oil	74.00	41.73 "	3.088 "
Aviation Turbo	70.84	35.93 "	2.545 "
Solid Fuels			
U.S. Bituminous	85.95	29.99 GJ/t	2.579 t/t
Cdn. Bituminous	86.72	29.30 "	2.541 "
Sub-Bituminous	94.20	19.76 "	1.861 "
Lignite	101.68	15.35 "	1.561 "
Anthracite	85.95	29.53 "	2.538 "
Fuel Wood	81.47	18 TJ/kt	1.47 t/t wood
Slash Burning	81.47	18 TJ/kt	1.47 t/t wood
Coke			2.39 t/t*

*See Section 4.1.4

TABLE 4.2.2

Fuel Combustion N_2O Emission Factors

Fuel Type	as N_2		as N_2O	
	kg/t[a]	kg/m^3 [b]	kg/t	kg/m^3
Gaseous Fuels				
Natural Gas	0.0178	1.39×10^{-5}		2.2×10^{-5}
Liquid Fuels				
Light Oil	0.0890	0.0801		.13
Heavy Oil	0.0890	0.0846		.13
Gas - no catalyst	0.1873	0.1405		.22
- new catalyst	0.3602	0.2702		.42
- aged catalyst	1.1931	0.8948		1.4
Diesel	0.2923	0.2543		.40
Solid Fuels				
Coal	0.0680		0.11[c]	
Wood	0.1		0.16	
Coke			0.11[d]	

Notes:

a From Jaques 1991
b Converted using data from Jaques 1990
c For coal combustion except Electric Power Generation
d See Section 4.1.4

point	area
coal	coal
distillate oil	distillate oil
residual oil	residual oil
natural gas	natural gas
other - process gas	other - kerosene
- wood/bark waste	
- solid waste	
- coke	
- propane	
- butane	

Specific SCCs and SCs assigned to these categories are summarized in Table 5.1.4. Liquid waste combustion (SCC 102013-01) involved only spent liquor combustion, which was inventoried as a process related source (Section 4.1.3).

Emission factors were assigned on the basis of the fuel combusted (see Table 4.2.1 and 4.2.2), as summarized in Table 5.1.2 (a and b).

No additions or revisions were made to the MOE files, other than to fill in missing base quantities.

4.2.3 Commercial Fuel Combustion

Commercial fuel combustion includes the following categories of point and area sources in the MOE system:

point	area
coal	distillate oil
distillate oil	residual oil
residual oil	natural gas
natural gas	
other - process gas	other - kerosene
- propane	- bottled gas
- solid waste	
- liquid waste	

Specific SCCs and SCs included in these categories are listed in Table 5.1.4.

Emission factors for CO_2 and N_2O (see Tables 4.2.1 and 4.2.2) were assigned on the basis of the fuel combusted, as summarized in Table 5.1.2 (a and b).

No additions or revisions were made to these files other than to fill in missing base quantities as possible.

4.2.4 Residential Fuel Combustion

This sector consists of area sources (single and multiple dwellings) burning residual oil, distillate oil or natural gas (see Table 5.1.2 (a) and 5.1.4).

CO_2 and N_2O emission factors as summarized in Tables 4.2.1 and 4.2.2,.were assigned according to the fuel combusted.

No additions or revisions were made to these MOE base quantity files.

4.2.5 Residential Fuelwood Combustion

This area source (SC 54) was inventoried using wood-based emission factors for CO_2 and N_2O (see Tables 4.2.1 and 4.2.2).

No revisions were made to this MOE base quantity file.

4.2.6 Pipelines

1083.8 GL of natural gas were used for pipeline compressors in Ontario in 1988 (Statistics Canada, Publication No. 57-003). No SC was previously available in the MOE inventory system for this sector and SC 139 was assigned. In order to derive base quantities, pipeline routes were mapped for Ontario (National Atlas of Canada, 5th Edition) and assigned to grids based on the estimated length in each grid. The total natural gas use was assumed to be distributed evenly over these routes, based on kilometres of pipeline summed for each grid (8778 km in total). The emission factors for CO_2 and N_2O are based on the combustion of natural gas and are expressed in terms of t (or kg)/km, respectively.

4.3 Transportation

4.3.1 Highway Gasoline and Diesel Fuel Use

The emission rate of CO_2 from highway motor vehicles is a function of the fuel economy (km/l) and fuel characteristics (grams of carbon per litre of fuel). (Black 1988). Rather than assuming all carbon is released as CO_2, it was decided, in consultation with MOE, to use a carbon balance which accounted for emissions of C as CO or as hydrocarbons. This approach is consistent with that of the U.S. EPA and other international studies.

The following algorithm was used in Mobile 4O (Ontario-specific version of Mobile 4) to derive a CO_2 emission factor, for each vehicle class, specific to the Ontario 1988 vehicle fleet (Black 1988):

$$CO_2\text{, g/km} = ((K_1 x FD\text{, g/L}) / FE\text{, km/L} - K_1 x HC\text{, g/km} - K_2 x CO\text{, g/km}) / K_3$$

where K_1 = carbon weight fraction of fuel = .866
K_2 = carbon weight fraction of CO = .429
K_3 = carbon weight fraction of CO_2 = .273
FD = fuel density
FE = fuel economy
HC = emission factor for HC in g/km
CO = emission factor for CO in g/km

Fuel carbon weight percents of 86.6 and 87.2 were used for gasoline and diesel, respectively. These represented the high end of the range found in the literature in order to be conservative.

The CO_2 emission factors calculated in this manner are presented in Table 4.3.1.

N_2O emission factors are based on the emission factors in an Environment Canada report (Jaques 1991), as discussed in Section 4.2. These emission factors were converted from a volume of fuel use basis to a vehicle kilometer travelled basis, using the following data (Jaques 1990):

Vehicle Class	Fuel Economy (km/L)
LDGV	8.512
LDDV	5.886
LDGT	4.707
HDGV	2.619
HDDV	3.274
MTC	14.15

For light and medium-duty vehicles, it was assumed that 10% of VKmT were by vehicles - no catalyst, 20% by vehicles-new catalyst and 70% by vehicles - aged catalyst (Jaques 1991).

N_2O factors derived using the above information are listed in Table 4.3.1.

All base quantities for highway travel were taken from MOE area source base quantity files (see Table 5.1.2a and 5.1.4 for specific SCs).

4.3.2 Railroads

Emissions of CO_2 and N_2O from railroads are inventoried by using fuel-based emission factors (see Tables 4.2.1 and 4.2.2). All fuel used is diesel. Railroad transportation is inventoried as an area source (see Table 5.1.2a and 5.1.4).

No revisions were made to the MOE base quantity file for this sector.

4.3.3 Marine

Vessels burning diesel oil and residual oil were inventoried using the appropriate CO_2 and N_2O fuel-based emission factors (see Table 4.2.1 and 4.2.2) and area source base quantities from the MOE base quantity file (see Table 5.1.2a and 5.1.4).

Pleasure craft could not be inventoried as emission factors were not available on a horsepower-hour basis (the units in which MOE currently gathers statistics on pleasure craft).

TABLE 4.3.1

CO_2 and N_2O Emission Factors for Highway Vehicles (Gasoline and Diesel)

Sector[1]	Vehicle Class	CO_2 Factor (t/1000 VkmT)[1]	N_2O Factor (kg/1000 VkmT)
Passenger - gas	LDGV	.2419	.13
Passenger - diesel	LDDV	.4699	.068
Taxis - gas	LDGV	.2419	.13
Taxis - diesel	LDDV	.4699	.068
LD Trucks - gas	LDGT1	.4559	.23
LD Trucks - diesel	LDDT	.4698	.068
MD Trucks - gas	LDGT2	.4477	.23
MD Trucks - diesel	LDDT	.4698	.068
HD Trucks - gas	HDGV	.7951	.084
HD Trucks - diesel	HDDV	.8329	.12
Buses - gas	HDGV	.7951	.084
Buses - diesel	HDDV	.8329	.12
Motorcycles	MC	.1417	.016
Highway Line		.3101	.15

1. LD = light duty
MD = medium duty
HD = heavy duty

VkmT = vehicle kilometres travelled

2. Highway Line Travel emission factors are based on the listed emission factors and the following percentages of total VkmT for the vehicle classes (ORF 1983):

LDGV	74.9
LDDV	1.4
LDGT	16.5
LDDT	.05
HDGV	2.5
HDDV	3.0
Motorcycles	1.6

4.3.4 Aircraft

MOE inventories four classes of aircraft as area sources, based on units of landing/take-off (LTO) cycles. No CO_2/N_2O emission factor data were found in terms of LTO cycles. However, data are available on total fuel use (aviation gasoline and aviation turbo-fuel) by aircraft in Ontario (Statistics Canada, Report No. 57-003). These data were used to estimate total CO_2 and N_2O emissions from aircraft in Ontario, as illustrated in Table 4.3.2, using fuel-based emission factors (see Tables 4.2.1 and 4.2.2). Note that the emission factor for turbo fuel was assumed to be the same as that for gasoline. LTO cycles were then assigned as either turbo fuel or gasoline, as illustrated in Table 4.3.2, and CO_2/N_2O emission factors derived. It should be noted that this method assigns all aircraft emissions (i.e., those that occur in-flight as well as during landing and take-offs) to the LTO cycle and also assumes that all aircraft classes use the same amount of fuel per LTO cycle.

No additions or revisions were made to the MOE base quantity files.

4.3.5 Off-Road Engines

Emissions of CO_2 and N_2O due to off-road transportation were inventoried for gasoline vehicles (agricultural engines) and diesel vehicles (agricultural, construction and industrial engines) using fuel-based emission factors (see Tables 4.2.1 and 4.2.2). Snowmobiles and lawnmowers could not be inventoried, as only the number of units were available in the MOE area source files and no annual fuel-use data for these engines were available for use in deriving a unit-based emission factor.

4.4 Incineration

4.4.1 Municipal Waste Incineration

CO_2 emissions from the combustion of municipal refuse in multiple-chamber or other incinerators, will depend on the carbon and energy content of the waste as well as the combustion efficiency. An emission factor of 0.902 t CO_2/t of urban refuse incinerated was derived by Environment Canada, based on the estimated thermal value of the waste from a reported range (i.e., approximately 35% of the calorific value of hard coal) (Jaques 1990). Due to the potential variability of this

TABLE 4.3.2

Aircraft Emission Factor Development

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1) Total CO_2/N_2O Emissions (Ontario) (see text)

Fuel	Ontario Fuel Use $10^3 m^3$	Emission Factor CO_2 (t/m^3)	Emission Factor N_2O (kg/m^3)	Total Emissions CO_2 (t)	Total Emissions N_2O (kg)
aviation gasoline	10.6	2.545	.2208	2.10×10^4	2.34×10^3
aviation turbo fuel	1342.8	2.325	.2208	3.12×10^6	2.96×10^5

2) LTO Cycles by Fuel Type

	Assumed # LTO Aviation gasoline	Assumed # LTO Aviation turbo fuel
Jets	-	170,817
Turbo	91 162	91 162
Piston	253 528	-
Helicopter	-	23 896

3) CO_2/N_2O Emission Factors (per LTO cycle)

	CO_2 (t/LTO)	N_2O (kg/LTO)
Jets	11.95	1.0
Turbo	6.013	.52
Piston	.07150	.0068
Helicopter	11.95	1.0

value, available Ontario source measurement data were used to substantiate the estimated emission factor. On the basis of several tests conducted at two municipal incinerators in Ontario (i.e., multiple chamber and RDF units) burning various types of wastes, a range of 0.99 to 1.2 t CO_2/t refuse incinerated has been derived (ORTECH 1987a, 1988b). It can be seen that the measured values were similar to the estimated emission factors. Point-specific CO_2 emission factors were, thus, applied to the individual incinerators and the estimated emission factor was applied to other municipal incinerators in Ontario. For lack of better information, the N_2O emission factor for wood combustion, reported by Environment Canada (Jaques 1991) was applied to all municipal incinerators (i.e., 0.16 kg N_2O/t wood burned). Base quantity data for individual point source municipal incinerators was available in MOE files.

4.4.2 Sewage Sludge Incineration

Sewage sludge is incinerated mainly in four multiple-hearth sewage sludge incinerators in Ontario. Due to the lack of reported CO_2 emission factors for this type of incinerator, source test data were used to derive an average factor. Source measurements were available for three of these facilities, and the average emission factor was found to be 0.66 t CO_2/t dry sludge incinerated with a range of 0.44 to 0.95 t CO_2/t dry sludge (ORTECH 1980, 1988c, 1989a and b). Accordingly, point-specific emission factors were applied to individual facilities and the average factor was applied to other sewage sludge incinerators in Ontario. The N_2O emission factor for wood combustion, reported by Environment Canada (i.e., 0.16 kg N_2O/t wood burned), was used in all cases in order to derive an emission estimate for these sources (Jaques 1991). Base quantity data, in tonnes of dry sludge burned, was available in MOE files only for some of the sewage sludge incinerators in Ontario. Estimated quantities for the remaining units were assigned on the basis of throughputs reported during source measurements and estimated operating hours.

4.4.3 Industrial Waste Incineration

Various types of industrial waste incinerators operate in Ontario that range from small single chamber units to rotary kiln incinerators that burn wastes comprised of solid materials, sludges, paper and liquid wastes. Some may utilize a natural gas-fired afterburner and other types of control devices. No reported CO_2 or N_2O emission factors have been found from information reviewed. Only limited source test data were available for specific units in Ontario and emission factors derived from these measurements ranged from 0.55 to 2.47 t CO_2/t industrial waste burned (ORTECH 1987b, 1988d, 1989c). The lowest value corresponded to an industrial liquid waste incinerator and the highest to an incinerator burning wood, cardboard and paint sludge.

Point-specific CO_2 emission factors were applied to the particular incinerators in which measurements were conducted, and individual emission factors were applied to other facilities based upon assumptions of the types of wastes incinerated. An average factor of 0.9 t CO_2/t waste was applied to other facilities in which the types of wastes were not known. The N_2O emission factor for wood combustion, reported by Environment Canada, was used for all industrial waste incinerators. Only limited base quantity data for such incinerators were available in MOE point source files, and amounts of waste burned were estimated for a few specific facilities on the basis of throughputs reported during source testing and assumed operating hours.

4.4.4 Commercial/Institutional Waste Incineration

Numerous small single or dual chamber incinerators exist in Ontario that intermittently burn wastes generated at commercial or institutional facilities (e.g., universities, government buildings, etc.), or biomedical wastes generated at hospitals. There is a general lack of reported data pertaining to the amounts of wastes incinerated and emissions from such facilities, and no specific information was found regarding CO_2 and N_2O emission factors.

From other emission measurement requirements, several hospital incinerators in Alberta have been characterized with respect to the amounts of waste generated per day, the number of beds per hospital and the hourly waste feed rate to associated incinerators (Powell 1987). From these data, an average amount of 4 kg waste generated/bed/day was derived which corresponded to 1.454 tonnes waste/bed/year. This value was applied to 20 individual hospitals in Ontario known to operate incinerators in the Toronto, Hamilton, London and Ottawa areas, in order to estimate annual amounts of waste incinerated by facility (i.e., range of 150 to 1,600 tonnes waste/year). The number of beds for each of these hospitals, used in the estimate, was obtained from reported Hospital Statistics (Ont. Min. of Health, 1988). These data were entered as point sources to the MOE inventory data base. A theoretical emission factor of 1.47 t CO_2/t waste burned was derived from information in an MOE report, in which typical biomedical waste types were characterized (MOE 1986). The Environment Canada N_2O emission factor for wood combustion was also applied, in order to provide an estimate of nitrous oxide emissions (Jaques 1991). It should be noted that the emissions from these individual facilities represent only a fraction of the total emissions from commercial and institutional incinerators in Ontario which have yet to be identified.

4.4.5 Wigwam Burners

Wigwam or conical burners are used for the disposal of sawdust and other wood wastes in the lumber and plywood industries. An estimate of the amount of wood waste incinerated by such facilities is contained within the MOE area source files. Emission factors, reported by Environment Canada (i.e., 1.46 t CO_2/t wood and 0.16 kg N_2O/t wood burned), were applied to estimate emissions from wigwam burners (Jaques 1990 and 1991).

4.5 Miscellaneous and Open Sources

4.5.1 Anaesthetic Usage

Anaesthetic usage of nitrous oxide in the United States for 1989 is estimated to be 14,300 tonnes (Industry, Science and Technology Canada, private communication) or 57.8 g per capita based on a projected 1989 U.S. population of 247,500,000. Based on a 1988 Ontario population of 9.43 million, the total nitrous oxide emission from this source is estimated to be 545 tonnes N_2O. It is assumed that all nitrous oxide used for anaesthetic purposes is released to the atmosphere with negligible metabolism or other removal process.

The nitrous oxide releases due to anaesthetic usage were calculated using gridded population as a base quantity and the per capita emission factor.

4.5.2 Propellant Usage

Nitrous oxide used as a propellant for pressure and aerosol product in the United States for 1989 is estimated to be 750 tonnes (Industry, Science and Technology Canada, private communication) or 3.03 g per capita based on a projected 1989 U.S. population of 247,500,000. Based on a 1988 Ontario population of 9.43

million, the total nitrous oxide emission from this source is estimated to be 28.6 tonnes N_2O.

The nitrous oxide releases due to propellant usage were calculated using gridded population as a base quantity and the per capita emission factor.

4.5.3 Structural Fires

Amongst various types of incomplete combustion products, carbon dioxide emissions occur as a result of structural fires. CO_2 and N_2O emissions were estimated on the basis of emission factors reported by Environment Canada for wood combustion (i.e., 1.47 t CO_2/t wood and 0.16 kg N_2O/t wood) (Jaques 1990 and 1991) and the estimated mass of material burned in structural fires contained in MOE area source files.

4.5.4 Prescribed Fires

Prescribed fires or slash burning in northern parts of the province, controlled by the Ontario Ministry of Natural Resources, is conducted for three main reasons: to reduce the hazard of forest fires, to promote seedling growth and to control insects. An emission factor of 1.47 t CO_2/t wood burned has been used in the Environment Canada CO_2 inventory and also applied in the present inventory (Jaques 1990). The amount of slash burned in Ontario was available in the MOE area source file (i.e., 90309 tonnes). The resulting emissions (i.e., 132754 tonnes CO_2) were also compared with a method used in other studies from information provided by MOE (Yap 1991). For example, the CO_2 emissions were estimated from the products of: the mass of slash burned, the amount of carbon contained in the above-ground biomass (i.e., 45% for temperate and boreal forests), the fraction of carbon combusted with a corresponding fraction remaining on the ground as charcoal (i.e., 10%) and the ratio of the molecular weights for carbon dioxide and carbon. Accordingly, the slash burning CO_2 emissions were estimated to be:

$$\text{t } CO_2 \quad = \quad 90{,}309 \times 0.45 \times 0.90 \times 44/12 \quad = \quad 134{,}109 \text{ t } CO_2 \text{ emitted}$$

Hence, the two resulting values were found to be similar.

Emissions of N_2O due to slash burning were based upon the woodburning emission factor (i.e., 0.16 kg N_2O/t wood burned) reported by Environment Canada (Jaques 1991). This results in nitrous oxide emissions of 14.4 t due to slash burning in Ontario. Information obtained from MOE (Yap 1991) provided a method to derive N_2O emissions similar to the CO_2 emission approach, according to the product of the following components: the mass of slash burned, the carbon content of material burned, the relative nitrogen to carbon ratio of the fuel by weight (i.e., 1%), an emission ratio of N_2O release relative to the fuel nitrogen content (i.e., 0.005 to 0.009) and the molecular weight ratio of N_2O to N. The N_2O emission by this approach was estimated to be::

$$\text{t } N_2O = 90{,}309 \times 0.45 \times 0.01 \times 0.009 \times 44/28 = 5.7 \text{ tonnes}$$

It can be seen that a factor of three difference exists between the emission factor and mass approaches. It is possible that the wood burning emission factors may somewhat overestimate the N_2O emissions. This requires further examination to resolve the apparent differences.

4.5.5 Forest Fires

Natural forest fires are known to represent a significant source of CO_2 emissions. The woodburning emission factors for both CO_2 and N_2O, reported by Environment Canada, were applied to base quantity data contained in MOE files in tonnes of forest wood burned. On the basis of these emission factors, the provincial total CO_2 and N_2O emissions due to forest fires were estimated to be 12.6 x 106 t CO_2 and 1,373 t N_2O, respectively. As noted in Section 4.5.4, these emission estimates were compared with information provided by MOE on an alternative calculation approach (Yap 1991). The resulting emissions, calculated by this alternative approach were found to be similar for CO_2 and lower for N_2O.

4.5.6 Landfills

Emission factor:

U.S. EPA (1988) provides a compilation of data on the rate of landfill gas production and composition for the United States. The data show a strong dependance on the moisture content of the waste with no clear dependance on latitude. In wet regions, a mean gas production rate of 13.1 +/- 7.6 m^3/(tonne waste - year) is reported; this factor is based on total waste landfilled without any decay. The carbon dioxide content of the landfill gas varies as bacterial activity changes from aerobic to anaerobic. Over the life of the landfill, the CO_2 content of the gas is approximately 50% which results in a mean emission factor of 12.9 kg CO_2/(tonne waste - year).

EAG (1984) used a methane emission factor of 7.16 kg/(tonne - year) where the tonnes of waste are calculated using a half-life of 25 years. Assuming that the gas is 50% each of methane and carbon dioxide, the CO_2 emission factor is estimated to be 19.7 kg/(tonne decayed waste - year) which is consistent with the U.S. EPA factor based on total waste landfilled.

Base quantity:

The methodology used in deriving the amount of actively decaying waste in Ontario landfills, is based on the method used by EAG (1984) for VOC.

For this method, a per capita waste production of 1.9 kg per day from residential, commercial and industrial sources is assumed with 90% of this waste ending up in a landfill where it decays with a half-life of 25 years. Following the EAG (1984) methodology, it is estimated that at the end of 1988, there was a total of 101 million tonnes of actively decaying waste in Ontario landfills.

Emission calculation:

The annual total CO_2 emission from landfills in Ontario is estimated to be $101 \times 10^6 \times 19.7$ or 2 million tonnes CO_2 per year.

Geographical apportionment:

The Waste Management Branch of the Ontario Ministry of the Environment has prepared a record of all the open and closed landfills in Ontario. The record provides the locations of the landfills as well as the date of closing if inactive. The amount of waste landfilled at each site is not available. The total Ontario landfill emissions were distributed to the UTM grid using population as a surrogate parameter except that the population in any grid which contained no landfill was arbitrarily assigned to the nearest grid with a landfill; only landfill sites which are currently open or which were closed during the 1980's were considered. Older closed sites will have much reduced emissions. While this distribution method removes landfill emissions from those grids without a landfill, it does not ensure that the waste from the population in each grid is assigned to the correct landfill site. Hence, on a regional basis, the methodology is expected to provide consistent estimates of the emissions. The emissions from individual grid cells, however, should be used with caution. Proper assignment of waste to individual landfills would have to be based on landfill records or historical waste collection data and the routing of waste for disposal; such detailed gridding is beyond the scope of the present study.

4.5.7 Soils

Nitrous oxide emissions from soils occur as a result of biogenic activity within the soils. Both nitrification and denitrification reactions can occur; nitrification involves the formation of nitrates from other fixed forms of nitrogen such as ammonia or urea while denitrification is the progressive bio-reduction of nitrates to nitrite, NO, N_2O and finally N_2. In both nitrification and denitrification, nitrous oxide forms as an intermediate product, part of which is further transformed in the soil to nitrates or nitrogen. Some of the nitrous oxide formed, however, is removed from the soil by diffusion to the surface and so to the atmosphere.

The soil conditions which effect the rates of nitrification and denitrification are those which typically affect bacterial activity; for example, pH, moisture, temperature, oxygen availability (or absence thereof, if anaerobic), and the availability of carbon sources and other nutrients.

a) Nitrous Oxide Emissions from Cultivated Soils:

In agricultural soils, when fertilizer is applied, nitrous oxide emissions are observed to increase indicating that the production of nitrous oxide is at least partly limited by the availability of either nitrate, ammonia or other forms of fixed soil nitrogen. A close relationship between rate of fertilizer application, fertilizer type and rate of nitrous oxide emission from soils is, therefore, expected. Such a relationship has been observed in the results of many studies. Eichner(1990) has reviewed the available literature and published a comprehensive summary of emissions data for nitrous oxide from fertilized soils. Eichner's review shows that the emission rates cover a wide range; much of the variability may be attributable to variations in soil type and condition, moisture content, pH etc. Nonetheless, important averaged trends and relationships are evident in the data.

Emission factors:

Eichner's review provides data from some fourteen studies leading to a summary table of emission factors according to type of fertilizer applied. Emissions are expressed as the percentage applied fertilizer nitrogen which is evolved as nitrous oxide. The following table is extracted from Eichner (1990):

Fertilizer Type	Percent of N Fertilizer Evolved as N-N_2O		
	Range %	Median %	Average %
anhydrous ammonia	0.86-6.84	1.63	2.70
ammonium nitrate	0.04-1.71	0.12/0.40	0.44
other ammonium	0.02-0.90	0.12	0.25
urea	0.07-0.18	0.11/0.11	0.11
nitrates	0.001-0.50	0.03	0.07

From Eichner's data summary it is seen that there is a wide spread in the data and clearly there are other factors other than fertilizer type which have important influences on the nitrous oxide emissions. There is, however, a clear trend in the average values according to the type of fertilizer used. The average emission factors in the above table have been used in this study. For mixed fertilizers a value of 0.10% fertilizer N evolved as N_2O is assumed.

Fertilizer Base Quantities:

The annual total fertilizer use in Ontario for the years 1987/88 was obtained from the Fertilizer Institute of Ontario (private communication); the estimates (tonne N) are as follows:

Type of Fertilizer	Tonne N in Fertilizer	Tonne N_2O-N Emitted	Tonne N_2O Emitted
anhydrous ammonia	25807	697	1095
urea	81454	90	140
ammonium nitrate	21899	96	150
solutions	34093	150	236
ammonium sulphate	523	1	2
monoammonium phosphate	9894	25	39
diammonium phosphate	17972	45	71
10-34-0	28	0	0
	191670	1104	1733

Emissions calculation:

The N_2O-N emissions in the second column of the above table are obtained by applying the average emission factors from Eichner (1990) according to fertilizer type. The total estimated annual nitrous oxide emission due to fertilizer application in Ontario for 1987/88 is 1733 tonne N_2O.

Geographical apportionment:

The distribution of fertilizer use in Ontario is confidential and accordingly not available. For this study, the emissions have been distributed to the UTM grid using agricultural land-use statistics.

b) Nitrous Oxide from Natural Soils:

Galbally (1985) provides a review of the emissions of nitrogen to the atmosphere. Included in the review is a listing of available measurements of nitrous oxide emissions from a selection of ecosystems ranging from tropical to tundra and alpine. As was observed for cultivated lands, there was a wide range of measured emission rates for similar types ecosystem.

Emission factors:

The following table gives Galbally's summary of emission factors (g N_2O-N/(m^2-year)):

Forest:	
tropical	0.2
temperate	0.007 - 0.09
Woodlands, Shrub, Grasslands:	
tropical	0.01 - 0.1
temperate	0 - 0.1
Swamps, Meadows	0.01 - 0.05

The temperate forest data in the above table are from a forested area in New York (0.09) and the Hubbard Brook Forest in New Hampshire (0.007).

Other data which were obtained in Wisconsin and which could reasonably apply in Ontario, result from a study by Goodroad and Keeney (1984). Measurements were taken twice daily between April and October during daylight hours. The lack of night measurements may overstate the emissions on an annual basis. The following results were obtained (g N_2O-N/(m^2-year)):

Forests		
	deciduous	0.08
	coniferous	0.21
Prairie		
	burned	0.011
	unburned	0.010
Organic Soils		
	drained marsh	0.74
	undrained marsh	0.006
	wet meadow	0.14

These data are not inconsistent with those of Galbally. It is noted that the emission rate for coniferous forest from Goodroad and Keeney is higher; however, these authors indicate the replanted forest used in their study had higher emission rates than other data from natural forest. The high value obtained for drained swampland is thought to again reflect the higher nitrogen emission rates observed in disturbed soils.

In a study by Bowden et al (1990), nitrous oxide fluxes were measured from soils in a red pine plantation and a mixed hardwood forest in Massachusetts. The emission rates were found to be 0.001 and 0.0017 g N_2O-N/(m^2-yr) which are at least an order of magnitude lower than the mean estimates of Galbally. Bowden et al also found that the rates of nitrification in the forest soils studied were very low which apparently limited the nitrous oxide production; other studies which showed higher rates of nitrification had higher emission rates.

From the published data it is clear that the nitrous oxide emission from soils is a complex process. While temperature and soil moisture do affect the production of nitrous oxide in the soil, these parameters are of less importance where the production is limited by nitrate availability such as in the Bowden et al (1990) study where no relationship with either temperature or soil moisture was found. For the present study, emissions from natural soils in Ontario have been estimated on the basis of four land-use categories with the following emission factors:

coniferous	0.004 g N_2O-N/(m^2-yr)	0.006 g N_2O/(m^2-yr)
deciduous	0.01	0.016
swamplands	0.02	0.031
grasslands	0.05	0.079

Grasslands in Ontario are invariably the result of forest clearing. Cultivated land is treated separately according to fertilizer usage.

Base quantity data:

For both cultivated and natural soils, the areas of cultivated land, natural forests and grasslands on the UTM Ontario grid are required. Land-use data on a 1/6 x 1/4 degree lat-long grid prepared by Argonne National Laboratories were used below a latitude of 54 degrees and Sirois and Voldner (1984) were used for higher latitudes.

4.5.8 Respiration

a) Human Respiration

Emission factor:

Carbon dioxide produced as a result of respiration can be estimated using typical values for respiration rate and CO_2 concentration in exhaled air. From Hawke et al (1954) and Altman et al (1958), a typical carbon dioxide concentration in exhaled air for humans is approximately 4%. A second estimate of the exhaled CO_2 concentration can be made by noting that the human body controls respiration to maintain the partial pressure of CO_2 in the alveoli in the range of 40-45 mm Hg (Encyclopaedia Britannica). The alveoli comprise approximately 2/3 of the respired air volume (tidal volume); the remainder being inactive space such as the bronchi and trachea. On this basis, the exhaled air contains typically 3.5-4% carbon dioxide which is in good agreement with the 4% from Hawke et al.

Clearly, the breathing rate will depend on the age of the individual and activity being performed. For an adult, typical breathing rates at rest, during light work and heavy work are 7.4, 29 and 43 litres/minute, respectively (Altman et al 1958). For this study, a typical average respiration rate for all activities is assumed to be 18 litre of air per minute. At 4% CO_2, this represents an annual emission of 660 kg CO_2 per person.

Base Quantity and emission calculation:

Based on the Ontario population for 1988 of 9.43 million, the annual carbon dioxide emission due to human respiration is estimated to be 6.22 million tonnes.

Geographical apportionment:

The Ontario total human respiration emission was distributed to the UTM grid using gridded population data.

b) Domestic Animal Respiration

Emission factor:

Altman et al (1958) provide some data for the respiration of animals on the basis of activity and age. The breathing rates of domestic animals range from 5.7 litres/min for a sheep to 114 litres/min for a Holstein cow. The percentage of carbon dioxide in the exhaled air of animals is less variable and has been assumed constant at 4% in this study. Based on these data, the following CO_2 emission factors are used for animal respiration:

Cattle	3.6 tonnes CO_2/year per animal
Pig	1.6
Sheep	0.24

Base quantities:

The following animal counts were obtained from the Ontario Ministry of the Environment's emissions data base:

Cattle	2,987,000
Pigs	3,135,000
Sheep	192,300

These estimates were used directly in this study.

Emissions calculation:

Using the above emission factors and animal numbers provides the following emission estimates:

Cattle	10.8 million tonnes CO_2/year
Pigs	5.0
Sheep	0.05

Geographical apportionment:

The animal numbers are available in the MOE files gridded to the UTM grid facilitating direct geographical apportionment.

5. Inventory Results

5.1 Source Profile Assignments and Emission Factors

The emission profiles used in the CO_2/N_2O inventory are summarized in Table 5.1.1. The derivation of these profiles is outlined in Chapter 4, on a sector by sector basis.

Emission profiles were assigned a 3-digit identification number (EMID) using the following system:

EMID	Category
1XX	Stationary Fuel Combustion
2XX	Transportation
3XX	Incineration
4XX	Industrial Process
5XX	Open Sources
6XX	Plant Specific

CO_2 emission factors are in units of t/(base quantity); N_2O is in units of kg/(base quantity). Examples of base quantity units are:

mass - tonnes
volume - m^3
vehicle miles travelled - 1000 VkmT
distance - kilometres

Plant-specific emission factors have a brief description (i.e., lime for lime kilns) with the MOE point identification number (PID).

The emission profiles were assigned to all SCs (area) and SCCs (points) as summarized in Tables 5.1.2a and b. Plant-specific profiles (series 600) were assigned as overrides to the default EMID. Base quantities by SC/SCC are also provided. Plant-specific base quantities are included in the total for the SCC listed with the default EMID.

All SC descriptions in Tables 5.1.1 and 5.1.2 are as provided by MOE. The SCC descriptions used were from in-house data when available.

TABLE 5.1.1 Report on Emission Profiles

	Carbon Dioxide			Nitrous Oxide		
EMID	Profile Name	Emission Factor	Units	Profile Name	Emission Factor	Units
100	COAL COMB.-BIT/A	2.541	t/t	COAL COMB.-BIT/A	0.11	kg/t
101	COAL COMB.-LIG	1.561	t/t	COAL COMB.-LIG	0.11	kg/t
102	COKE COMBUSTION	2.541	t/t	COKE COMBUSTION	0.11	kg/t
103	COAL COMB-BIT-EL	2.541	t/t	COAL COMB-BIT-EL	0.29	kg/t
104	COAL COMB-LIG-EL	1.561	t/t	COAL COMB-LIG-EL	0.29	kg/t
110	RESIDUAL OIL COM	3.088	t/m3	RESIDUAL OIL COM	0.13	kg/m3
111	DISTILLATE OIL CO	2.828	t/m3	DISTILLATE OIL CO	0.13	kg/m3
112	DIESEL COMB.	2.734	t/m3	DIESEL COMB.	0.4	kg/m3
113	GASOLINE COMB.	2.356	t/m3	GASOLINE COMB.	0.22	kg/m3
114	KEROSENE COMB.	2.549	t/m3	KEROSENE COMB.	0.13	kg/m3
115	BOTL. GAS COMB.	1.528	t/m3			
120	NATURAL GAS COM	0.00189	t/m3	NATURAL GAS COM	2.2E-05	kg/m3
130	WOOD COMB.	1.47	t/t	WOOD COMB.	0.16	kg/t
140	S.PULP.LIQ - COMB.	1.503	t/t	S.PULPING - COMB.	0.16	kg/t
201	GASOLINE MOB-LD	0.2419	t/1000 VKMT	GASOLINE MOB-LD	0.13	kg/ 1000 VKM
202	GASOLINE MOB-LD	0.4559	t/1000 VKMT	GASOLINE MOB-LD	0.23	kg/ 1000 VKM
203	GASOLINE MOB-MD	0.4477	t/1000 VKMT	GASOLINE MOB-MD	0.23	kg/ 1000 VKM
204	GASOLINE MOD-HD	0.7951	t/1000 VKMT	GASLOINE MOD-HD	0.084	kg/ 1000 VKM
205	GASOLINE MOB-MB	0.1417	t/1000 VKMT	GASOLINE MOB-MB	0.016	kg/ 1000 VKM
210	DIESEL MOB-LDV	0.4669	t/1000 VKMT	DIESEL MOB-LDV	0.068	kg/ 1000 VKM
211	DIESEL MOB-LDT/M	0.4698	t/1000 VKMT	DIESEL MOB-LDT/M	0.068	kg/ 1000 VKM
212	DIESEL MOB-HDT/B	0.8329	t/1000 VKMT	DIESEL MOB-HDT/B	0.12	kg/ 1000 VKM
220	MOBILE-OTHER	0.3101	t/1000 VKMT	MOBILE-OTHER	0.15	kg/1000 VKM
230	AIRCRAFT-JET	11.954	LTO cycles	AIRCRAFT-JET	1	LTO cycles
231	AIRCRAFT-TURBO	6.013	LTO cycles	AIRCRAFT-TURBO	0.52	LTO cycles
232	AIRCRAFT-PISTON	0.0715	LTO cycles	AIRCRAFT-PISTON	0.0068	LTO cycles
233	AIRCRAFT-HELI	11.954	LTO cycles	AIRCRAFT-HELI	1	LTO cycles
310	MUN. WASTE INCIN.	0.903	t/t	MUN. WASTE INCIN.	0.16	kg/t
320	SEWAGE SLUDGE IN	0.66	t/t	SEWAGE SLUDGE IN	0.16	kg/t
330	IND. WASTE - INCIN.	0.9	t/t	IND. WASTE - INCIN.	0.16	kg/t
340	WASTE INCIN - BIO	1.47	t/t	WASTE INCIN - BIO	0.16	kg/t
400	CEMENT KILN-PROC	0.5	t/t			
401				NITRIC ACID PROD.	3.44	kg/t
402	AMMONIA PLANTS	1.56	t/t(product)			
403	LIME KILN	0.85	t/t(lime prod.)			
404	LIME KILN(CAPTIVE	0.2	t/t(air d. pul)			
405	COKE PRODUCTION	2.39	t/t(coal charg)	COKE PRODUCTION	0.11	kg/t(coal char)
406				ADIPIC ACID PROD.	300	Kg/t (ad. acid)
500				FERTILIZED SOILS	9.04	kg/t(as N)
501	LANDFILLS	0.0197	t/t(active)			
502				ANAESTH. GAS USA	0.0578	kg/capita
503				PROPELLANT USAG	0.00303	kg/capita
504	NATURAL GAS PIPE	233.4	t/km pipeline	NATURAL GAS PIPE	2.716	kg/km pipeline
510	RESP. - HUMANS	0.66	t/capita			
511	RESP. - CATTLE	3.6	t/cow			
512	RESP. - PIGS	1.6	t/pig			
513	RESP. - SHEEP	0.24	t/sheep			
520				NAT. SOIL - CONIF. F	6	kg/km2
521				NAT. SOIL - DECID.	16	kg/km2
522				NAT. SOIL - SWAMP	31	kg/km2
523				NAT. SOIL - GRASSL	79	kg/km2
601	LIME - PID=502501	0.85	t/t			

TABLE 5.1.1 Report on Emission Profiles

	Carbon Dioxide			Nitrous Oxide		
EMID	Profile Name	Emission Factor	Units	Profile Name	Emission Factor	Units
602	LIME - PID=100622	0.85	t/t			
603	LIME - PID=100022	0.85	t/t			
604	LIME - PID=200857	0.92	t/t			
605	LIME - PID=500165	0.85	t/t			
606	LIME - PID=200064	0.92	t/t			
607	LIME - PID=200068	0.85	t/t			
608	LIME - PID=500166	0.85	t/t			
609	LIME - PID=300016	0.79	t/t			
610	INC. - PID=100020	2.47	t/t	INC. - PID=100020	0.16	kg/t
611	INC. - PID=100025	0.55	t/t	INC. - PID=100025	0.16	kg/t
612	INC. - PID=100044	0.55	t/t	INC. - PID=100044	0.16	kg/t
613	INC. - PID=303905	2.47	t/t	INC. - PID=303905	0.16	kg/t
614	INC. - PID=100623	0.55	t/t	INC. - PID=100623	0.16	kg/t
615	INC. - PID=402402	0.55	t/t	INC. - PID=402402	0.16	kg/t
616	SEWAGE - PID=20640	0.58	t/t	SEWAGE - PID=20640	0.16	t/t
617	SEWAGE - PID=30640	0.44	t/t	SEWAGE - PID=30640	0.16	kg/t
618	SEWAGE - PID=30056	0.95	t/t	SEWAGE - PID=30056	0.16	kg/t
619	WASTE - PID=206406	1.1	t/t	WASTE - PID=206406	0.16	kg/t
620	WASTE - PID=300010	0.986	t/t	WASTE - PID=300010	0.16	kg/t

SC Code	Description	Base Quantity	Units	EMID	Profile Name
1	PASSENGER (Gasoline)	49,781,598	1000 VKMT	201	GASOLINE MOB-LDV
2	PASSENGER (Diesel)	938,331	1000 VKMT	210	DIESEL MOB-LDV
3	TAXIS (Gasoline)	3,573,768	1000 VKMT	201	GASOLINE MOB-LDV
4	TAXIS (Diesel)	67,349	1000 VKMT	210	DIESEL MOB-LDV
5	LD TRUCKS (Gasoline)	5,827,034	1000 VKMT	202	GASOLINE MOB-LDT
6	LD TRUCKS (Diesel)	379,676	1000 VKMT	211	DIESEL MOB-LDT/MDT
7	MD TRUCKS (Gasoline)	5,009,788	1000 VKMT	203	GASOLINE MOB-MDT
8	MD TRUCKS (Diesel)	1,076,714	1000 VKMT	211	DIESEL MOB-LDT/MDT
9	HD TRUCKS (Gasoline)	195,502	1000 VKMT	204	GASOLINE MOD-HDT/BUS
10	HD TRUCKS (Diesel)	4,123,390	1000 VKMT	212	DIESEL MOB-HDT/BUS
11	BUSES (Gasoline)	123,357	1000 VKMT	204	GASOLINE MOD-HDT/BUS
12	BUSES (Diesel)	275,404	1000 VKMT	212	DIESEL MOB-HDT/BUS
13	MOTOCYCLE (Gasoline)	305,329	1000 VKMT	205	GASOLINE MOB-MBIKE
20	AGRI.ENG. (Gasoline)	264,385	1000 LITRES	113	GASOLINE COMB.
21	AGRI.ENG. (Diesel)	249,407	1000 LITRES	112	DIESEL COMB.
22	CONST.ENG.(Diesel)	236,308	1000 LITRES	112	DIESEL COMB.
23	INDUS.ENG.(Diesel)	337,701	1000 LITRES	112	DIESEL COMB.
28	RAILROAD (Diesel)	646,308	1000 LITRES	112	DIESEL COMB.
33	AIRCRAFTS-Jets	170,817	LTO CYCLE	230	AIRCRAFT-JET
34	AIRCRAFTS-Turbo	182,323	LTO CYCLE	231	AIRCRAFT-TURBO
35	AIRCRAFTS-Piston	253,528	LTO CYCLE	232	AIRCRAFT-PISTON
36	AIRCRAFTS-Helicopters	23,896	LTO CYCLE	233	AIRCRAFT-HELI
38	SHIPPING (Diesel)	157,902	1000 LITRES	112	DIESEL COMB.
39	SHIPPING (Res.Oil)	251,396	1000 LITRES	110	RESIDUAL OIL COMB.
50	RES. SD (Dist.Oil)	1,125,841	1000 LITRES	111	DISTILLATE OIL COMB.
51	RES. SD (Kerosine)	102,806	1000 LITRES	114	KEROSENE COMB.
52	RES. SD (Nat. Gas)	5,354,649,000	M3	120	NATURAL GAS COMB.
53	RES. SD (Botl.Gas)	118,807	CUBIC MET	115	BOTL. GAS COMB.
54	RES. SD (Wood)	2,042,121	TONNES	130	WOOD COMB.
60	RES. MD (Dist.Oil)	281,458	1000 LITRES	111	DISTILLATE OIL COMB.
61	RES. MD (Nat. Gas)	1,338,667,000	M3	120	NATURAL GAS COMB.
62	RES. MD (Resi.Oil)	4,802	1000 LITRES	110	RESIDUAL OIL COMB.
65	COM/INS. (Dist.Oil)	381,619	1000 LITRES	111	DISTILLATE OIL COMB.
66	COM/INS. (Kerosine)	33,719	1000 LITRES	114	KEROSENE COMB.
67	COM/INS. (Nat. Gas)	4,019,910,000	M3	120	NATURAL GAS COMB.
68	COM/INS. (Botl.Gas)	161,610	CUBIC MET	115	BOTL. GAS COMB.
69	COM/INS. (Resi.Oil)	80,409	1000 LITRES	110	RESIDUAL OIL COMB.
71	INDUSTR. (Dist.Oil)	12,419	1000 LITRES	111	DISTILLATE OIL COMB.
72	INDUSTR. (Kerosine)	1,347	1000 LITRES	114	KEROSENE COMB.
73	INDUSTR. (Nat. Gas)	630,799,000	M3	120	NATURAL GAS COMB.
75	INDUSTR. (Resi.Oil)	54,770	1000 LITRES	110	RESIDUAL OIL COMB.
78	INDUSTR. (Bituminous)	359,667	TONNES	100	COAL COMB.-BIT/ANTH
79	MUN.WST. (Open Pit)	34,895	TONNES	310	MUN. WASTE INCIN.
80	MUN.WST. (Refuse)	373,986	TONNES	310	MUN. WASTE INCIN.
81	MUN.WST. (Sew.Sludge)	123,198	TONNES	320	SEWAGE SLUDGE INCIN.
82	IND.WST. (Wood Incin)	546,468	TONNES	130	WOOD COMB.
83	IND.WST. (Gas Incin)	86,169,000	M3	120	NATURAL GAS COMB.
85	APT. INCIN.	42,126	TONNES	310	MUN. WASTE INCIN.
86	WOOD WST.(Boilers)	957,577	TONNES	130	WOOD COMB.
87	FOREST FIRES	8,582,834	TONNES	130	WOOD COMB.
88	STRUCTURAL FIRES	145,932	TONNES	130	WOOD COMB.
89	PRESCRIBED FIRES	90,309	TONNES	130	WOOD COMB.
90	MAJOR HIGHWAYS	20,372,169	1000 VKMT	220	MOBILE-OTHER

TABLE 5.1.2A Report On Area Sources Profile Assignments (By Sector Code)

SC Code	Description	Base Quantity	Units	EMID	Profile Name
91	OTHER HIGHWAYS	8,880,453	1000 VKMT	220	MOBILE-OTHER
93	FERTILIZED SOILS	191,670	TONNES FE	500	FERTILIZED SOILS
119	LANDFILLS	101,000,003	TONNES	501	LANDFILLS
126	ANIMALS - CATTLE	2,986,594	CATTLE	511	RESP. - CATTLE
127	ANIMALS - PIGS	3,135,321	PIG	512	RESP. - PIGS
128	ANIMALS - SHEEP	192,260	SHEEP	513	RESP. - SHEEP
139	PIPLINES (COMPRESS	8,778	km (Pipeline)	504	NATURAL GAS PIPELINE
140	ANAESTHETIC GAS US	9,431,000	CAPITA	502	ANAESTH. GAS USAGE
141	PROPELLANT USAGE	8,634,865	CAPITA	503	PROPELLANT USAGE
142	RESPIRATION - HUMA	9,431,000	CAPITA	510	RESP. - HUMANS
143	NATURAL SOILS - CO	446,057	sqkm (Land)	520	NAT. SOIL - CONIF. F
144	NATURAL SOILS - DEC	91,151	sqkm (Land)	521	NAT. SOIL - DECID. F
145	NATURAL SOILS - SW	282,000	sqkm (Land)	522	NAT. SOIL - SWAMP
146	NATURAL SOILS - GR	28,272	sqkm (Land)	523	NAT. SOIL - GRASSLA.

TABLE 5.1.2B Report on SCC Codes and Profile Assignments

SCC Code	SCC Description	Base Quantity	Units	EMID	Profile Name
10100201	EXTCOMB BOILER ELECTRIC GENERATNBITUMINOUS COAL PULV COAL WET BOT	611,928	t	100	COAL COMB -BIT/ANTH
10100201	EXTCOMB BOILER ELECTRIC GENERATNBITUMINOUS COAL PULV COAL WET BOT	10,160,694	t	103	COAL COMB BIT EL PW
10100301	EXTCOMB BOILER ELECTRIC GENERATNLIGNITE PULVERIZED COAL	1,234,652	t	104	COAL COMB LIG EL PW
10100501	EXTCOMB BOILER ELECTRIC GENERATNDISTILLATE OIL NO 1 AND NO 2 OIL	43,938	m3	111	DISTILLATE OIL COMB
10100601	EXTCOMB BOILER ELECTRIC GENERATNNATURAL GAS >100MMBTU/HR EXTF	1,207,461	m3	120	NATURAL GAS COMB
10200201	EXTCOMB BOILER INDUSTRIAL BITUMINOUS COAL PULV COAL WET BOT	287,200	t	100	COAL COMB -BIT/ANTH
10200401	EXTCOMB BOILER INDUSTRIAL RESIDUAL OIL NO 6 OIL	720,942	m3	110	RESIDUAL OIL COMB.
10200404	EXTCOMB BOILER INDUSTRIAL RESIDUAL OIL NO 5 OIL	3,930	m3	110	RESIDUAL OIL COMB.
10200501	EXTCOMB BOILER INDUSTRIAL DISTILLATE OIL NO 1 AND NO 2 OIL	6,382,870	m3	111	DISTILLATE OIL COMB
10200504	EXTCOMB BOILER INDUSTRIAL DISTILLATE OIL NO 4 OIL	6,301	m3	111	DISTILLATE OIL COMB.
10200601	EXTCOMB BOILER INDUSTRIAL NATURAL GAS >100MMBTU/HR	3,376,620,339	m3	120	NATURAL GAS COMB
10200603	EXTCOMB BOILER INDUSTRIAL NATURAL GAS <10MMBTU/HR	602,405	m3	120	NATURAL GAS COMB
10200701	EXTCOMB BOILER INDUSTRIAL PROCESS GAS PETROL REFINERY	121,173,613	m3	120	NATURAL GAS COMB
10200799	EXTCOMB BOILER INDUSTRIAL PROCESS GAS OTHER/NOT CLASIFD	891,520,000	m3	120	NATURAL GAS COMB.
10200801		8,116	t	102	COKE COMBUSTION
10200802	EXTCOMB BOILER INDUSTRIAL COKE ALL BOILER SIZES	174,402	t	102	COKE COMBUSTION
10200901	EXTCOMB BOILER INDUSTRIAL WOOD/BARK WASTE BARK>50K LB STEAM	988,960	t	130	WOOD COMB
10200903	EXTCOMB BOILER INDUSTRIAL WOOD/BARK WASTE WOOD>50K LB STEAM	40,000	t	130	WOOD COMB
10201001	EXTCOMB BOILER INDUSTRIAL LIQ PETROLEUM GASBUTANE	38,817	m3	115	BOTL. GAS COMB
10201002	EXTCOMB BOILER INDUSTRIAL LIQ PETROLEUM GASPROPANE	3,853	m3	115	BOTL. GAS COMB.
10201201	EXTCOMB BOILER INDUSTRIAL SLD WASTE-SPECIFYSPEC MAT COMM FLD	31,946	t	130	WOOD COMB.
10201201	EXTCOMB BOILER INDUSTRIAL SLD WASTE-SPECIFYSPEC MAT COMM FLD	3,287	t	330	IND. WASTE - INCIN
10201201	EXTCOMB BOILER INDUSTRIAL SLD WASTE-SPECIFYSPEC MAT COMM FLD	34,000	t	615	INC. - PID=402402
10201301	EXTCOMB BOILER INDUSTRIAL LIQ WASTE-SPECIFYSPEC MAT COMM FLD	1,736,526	t	140	S PULPING - COMB.
10300201		6,531	t	100	COAL COMB.-BIT/ANTH
10300401	EXTCOMB BOILER COMMERCL-INSTUTNLRESIDUAL OIL NO 6 OIL	83,765	m3	110	RESIDUAL OIL COMB
10300404	EXTCOMB BOILER COMMERCL-INSTUTNLRESIDUAL OIL NO 5 OIL	3,256	m3	110	RESIDUAL OIL COMB
10300501	EXTCOMB BOILER COMMERCL-INSTUTNLDISTILLATE OIL NO 1 AND NO 2 OIL	96,078	m3	111	DISTILLATE OIL COMB
10300504	EXTCOMB BOILER COMMERCL-INSTUTNLDISTILLATE OIL NO 4 OIL	3,501	m3	111	DISTILLATE OIL COMB
10300601	EXTCOMB BOILER COMMERCL-INSTUTNLNATURAL GAS >100MMBTU/HR	283,444,729	m3	120	NATURAL GAS COMB
10300602	EXTCOMB BOILER COMMERCL-INSTUTNLNATURAL GAS 10-100MMBTU/HR	181,997,005	m3	120	NATURAL GAS COMB.
10300603	EXTCOMB BOILER COMMERCL-INSTUTNLNATURAL GAS <10MMBTU/HR	45,302,376	m3	120	NATURAL GAS COMB.
10300701	EXTCOMB BOILER COMMERCL-INSTUTNLPROCESS GAS SEWAGE GAS	1,793,302	m3	120	NATURAL GAS COMB
10301002	EXTCOMB BOILER COMMERCL-INSTUTNLLIQ PETROLEUM GASPROPANE	102	m3	115	BOTL. GAS COMB.
10301201	EXTCOMB BOILER COMMERCL-INSTUTNLSLD WASTE-SPECIFYSPEC MAT COMM FL	181	t	310	MUN. WASTE INCIN.
10301201	EXTCOMB BOILER COMMERCL-INSTUTNLSLD WASTE-SPECIFYSPEC MAT COMM FL	74	t	330	IND. WASTE - INCIN.
10301303	EXTCOMB BOILER COMMERCL-INSTUTNLLIQ WASTE-SPECIFYSEWAGE GREASE SK	8,804	t	320	SEWAGE SLUDGE INCIN
30100101	CHEMICAL MFG ORGANIC CHEMICALSADIPIC ACID PROD ALL ADIPC ACD FAC	38,000	t (ad. acid)	406	ADIPIC ACID PROD
30100399	CHEMICAL MFG AGRICULTURAL CHEMAMMONIA OTHER/NOT CLASI**	810,300	t(product)	402	AMMONIA PLANTS
30101301	CHEMICAL MFG AGRICULTURAL CHEMNITRIC ACID ABSRBR TAILGAS/OD	133,785	t	401	NITRIC ACID PROD.
30101399	CHEMICAL MFG AGRICULTURAL CHEMNITRIC ACID OTHER/NOT CLASI**	133,225	t	401	NITRIC ACID PROD
30190001	CHEMICAL MFG FUEL-FIRED EQPMNTPROCESS HEATERS DIST OIL(NO.2)	62	m3	111	DISTILLATE OIL COMB
30190003	CHEMICAL MFG FUEL-FIRED EQPMNTPROCESS HEATERS NAT GAS	3,357,300	m3	120	NATURAL GAS COMB
30300302	PRIMARY METALS IRON & STEEL BY-PRODUCT COKE OVEN CHARGING	3,634,980	t(coal char)	405	COKE PRODUCTION
30300304	PRIMARY METALS IRON & STEEL BY-PRODUCT COKE QUENCHING	1,851,880	t(coal char)	405	COKE PRODUCTION
30390004	PRIMARY METALS FUEL-FIRED EQPMNTPROCESS HEATERS PROCESS GAS	197,636,000	m3	120	NATURAL GAS COMB
30490001	SECONDARY METALS FUEL-FIRED EQPMNTPROCESS HEATERS DIST OIL(NO.2)	100	m3	111	DISTILLATE OIL COMB
30490003	SECONDARY METALS FUEL-FIRED EQPMNTPROCESS HEATERS NAT GAS	33,855,676	m3	120	NATURAL GAS COMB
30490004	SECONDARY METALS FUEL-FIRED EQPMNTPROCESS HEATERS PROCESS GAS	84,900	m3	120	NATURAL GAS COMB

TABLE 5.1.2B Report on SCC Codes and Profile Assignments

SCC Code	SCC Description	Base Quantity	Units	EMID	Profile Name
30500606	MINERAL PRODUCTS CEMENT MFG DRY PROCESS KILNS	2,655,149	t	400	CEMENT KILN PROCESS
30500706	MINERAL PRODUCTS CEMENT MFG WET PROCESS KILNS	2,882,910	t	400	CEMENT KILN-PROCESS
30501604	MINERAL PRODUCTS LIME MFG CALCINING ROTARY KILN	200,000	t	601	LIME - PID=502501
30501604	MINERAL PRODUCTS LIME MFG CALCINING ROTARY KILN	922,000	t	602	LIME - PID=100622
30501604	MINERAL PRODUCTS LIME MFG CALCINING ROTARY KILN	292,000	t	603	LIME - PID=100022
30501604	MINERAL PRODUCTS LIME MFG CALCINING ROTARY KILN	122,000	t	604	LIME - PID=200857
30501604	MINERAL PRODUCTS LIME MFG CALCINING ROTARY KILN	200,000	t	605	LIME - PID=500165
30501604	MINERAL PRODUCTS LIME MFG CALCINING ROTARY KILN	263,800	t	606	LIME - PID=200064
30501604	MINERAL PRODUCTS LIME MFG CALCINING ROTARY KILN	215,000	t	607	LIME - PID=200068
30501604	MINERAL PRODUCTS LIME MFG CALCINING ROTARY KILN	53,000	t	608	LIME - PID=500166
30501604	MINERAL PRODUCTS LIME MFG CALCINING ROTARY KILN	286,255	t	609	LIME - PID=300016
30590003	MINERAL PRODUCTS FUEL-FIRED EQPMNTPROCESS HEATERS NAT GAS	82,103,240	m3	120	NATURAL GAS COMB.
30590023	MINERAL PRODUCTS FUEL-FIRED EQPMNTFLARES NAT GAS	5,000,000	m3	120	NATURAL GAS COMB
30600103	PETROLEUM INDRY PETROLEUM REFNG PROCESS HEATERS OIL FIRED	3,856,225	m3	110	RESIDUAL OIL COMB
30600104	PETROLEUM INDRY PETROLEUM REFNG PROCESS HEATERS GAS FIRED	249,063,941	m3	120	NATURAL GAS COMB
30600105	PETROLEUM INDRY PETROLEUM REFNG PROCESS HEATERS NATURAL GAS-FIRED	50,549,999	m3	120	NATURAL GAS COMB.
30600106	PETROLEUM INDRY PETROLEUM REFNG PROCESS HEATERS PROCESS GAS-FIRED	673,384,787	m3	120	NATURAL GAS COMB
30600107	PETROLEUM INDRY PETROLEUM REFNG PROCESS HEATERS LPG FIRED	67,000	m3	115	BOTL. GAS COMB.
30600904	PETROLEUM INDRY PETROLEUM REFNG FLARES PROCESS GAS	7615638	m3	120	NATURAL GAS COMB
30700106	PULP & PAPER KRAFT PULPING LIME KILN GENERAL	2,081,564	t(air d pul)	404	LIME KILN(CAPTIVE P)
30990003	FABRICATED METALSFUEL FIRED EQPMNTPROCESS HEATERS NAT GAS	3579196	m3	120	NATURAL GAS COMB.
39000201	INDUSTRIAL PROCESINPROCESS FUEL BITUMINOUS COAL CEMENT KILN/DRYER	1,609,082	t	100	COAL COMB -BIT/ANTH
39000203	INDUSTRIAL PROCESINPROCESS FUEL BITUMINOUS COAL LIME KILN	1,060	t	100	COAL COMB -BIT/ANTH
39000403	INDUSTRIAL PROCESINPROCESS FUEL RESIDUAL OIL LIME KILN	7,416	m3	110	RESIDUAL OIL COMB.
39000503	INDUSTRIAL PROCESINPROCESS FUEL DISTILLATE OIL LIME KILN	380	m3	111	DISTILLATE OIL COMB.
39000602	INDUSTRIAL PROCESINPROCESS FUEL NATURAL GAS CEMENT KILN/DRYER	1,227,966	m3	120	NATURAL GAS COMB
39000603	INDUSTRIAL PROCESINPROCESS FUEL NATURAL GAS LIME KILN	1,342,016	m3	120	NATURAL GAS COMB
39000899	INDUSTRIAL PROCESINPROCESS FUEL COKE NOT CLASSIFIED	81,500	t	102	COKE COMBUSTION
40201001	ORGANIC SOLVENT SURFACE COATING OVEN HEATER NATURAL GAS	64	m3	120	NATURAL GAS COMB.
40201003	ORGANIC SOLVENT SURFACE COATING OVEN HEATER RESIDUAL OIL	8,804	m3	110	RESIDUAL OIL COMB
50100101	SOLID WASTE DISPLGOVERNMENT MUNICIPAL INCIN MULTIPLE CHAMBER	80,240	t	619	WASTE - PID=206406
50100101	SOLID WASTE DISPLGOVERNMENT MUNICIPAL INCIN MULTIPLE CHAMBER	168,800	t	620	WASTE - PID=300010
50100506	SOLID WASTE DISPLGOVERNMENT OTHER INCINERATORSLUDGE	30,827	t	320	SEWAGE SLUDGE INCIN
50100506	SOLID WASTE DISPLGOVERNMENT OTHER INCINERATORSLUDGE	12,300	t	616	SEWAGE - PID=206407
50100506	SOLID WASTE DISPLGOVERNMENT OTHER INCINERATORSLUDGE	34,570	t	617	SEWAGE - PID=306401
50100506	SOLID WASTE DISPLGOVERNMENT OTHER INCINERATORSLUDGE	21,900	t	618	SEWAGE - PID=300566
50100507	SOLID WASTE DISPLGOVERNMENT OTHER INCINERATORCONICAL-MUNICIPAL	17,000	t	310	MUN. WASTE INCIN
50200101	SOLID WASTE DISPLCOMMERCL/INSTITNLINCINERATION-GENLMULTIPLE CHAMBER	720	t	310	MUN. WASTE INCIN
50200505	SOLID WASTE DISPLCOMMERCL/INSTITNLINCINERATION-SPCLPATHOLOGICAL	14,170	t	340	WASTE INCIN - BIOMED
50300108	SOLID WASTE DISPLINDUSTRIAL INCINERATION AUTO BODY COMPONT	1,120	t	610	INC. - PID=100020
50300108	SOLID WASTE DISPLINDUSTRIAL INCINERATION AUTO BODY COMPONT	8,000	t	613	INC. - PID=303905
50300199		27	t	611	INC. - PID=100025
50300199		20,960	t	612	INC. - PID=100044
50300199		70,000	t	614	INC. - PID=100623

TABLE 5.1.4

SCC and SC Sector/Fuel Assignments

	Combustion							
Sector	Coal	Dist. Oil	Resid. Oil	Nat. Gas	Gasoline	Diesel	Other	Other Sourc
Industrial Process								
Cement Production								305006
Cement Production								305007
Lime Production								305016
Coke Production								303003
								303003
Ammonia Production								301003-
Nitric Acid Production								301027-
Pulp and Paper								307001-
Pulp and Paper								102013-
Adipic Acid								301001-
Stationary Fuel Combustion								
Electric Power Generation	101002-01	101005-01		101006-01				
	101003-01							
Industrial Fuel Combustion	102002-01	102005-01	102004-01	102006-01			102007-01	
Point	390002-01	102005-04	102004-04	102006-03			102007-04	
	390002-03	301900-01	306001-03	301900-03			102007-07	
		304900-01	390004-03	304900-03			102007-99	
		390005-03	402010-03	305900-03			102008-01	
				305900-23			102008-02	
				306001-04			102009-01	
				306001-05			102009-03	
				309900-03			102010-01	
				390006-02			102010-02	
				390006-03			102012-01	
				402010-01			303900-04	
							304900-04	
							306001-06	
							306001-07	
							306009-04	
							390008-99	

TABLE 5.1.4 (contd.)

SCC and SC Sector/Fuel Assignments

Sector	Coal	Dist. Oil	Resid. Oil	Combustion Nat. Gas	Gasoline	Diesel	Other	Other Source
Area	78	71	75	73			72	
Commercial Fuel Combustion								
Point	103002-01	103005-01 103005-04	103004-01 103004-04	103006-01 103006-02 103006-03			103007-01 103010-02 103012-01 103013-03	
Area		65	69	67			66 68	
Residential Fuel Combustion		50 60	62	52. 61			51 53	
Residential Fuel Wood							54	
Transportation								
Automobiles					1,3	2,4		
Light-Duty Trucks					5	6		
Medium-Duty Vehicles					7	8		
Heavy-Duty Vehicles					9,11	10,12		
Motorcycles					13			
Highway-Line					Special			
Railroads						28		
Marine			39			38		
Aircraft							33,34,35,36	
Off-Road					20	21,22,23		

TABLE 5.1.4 (contd.)

SCC and SC Sector/Fuel Assignments

Sector	Combustion Coal	Dist. Oil	Resid. Oil	Nat. Gas	Gasoline	Diesel	Other	Other Sourc
Incineration								
Municipal							501001-01 501005-07 502001-01 79,80,85	
Sewage Sludge							81 502005-06 501005-06	
Industrial Waste							503001-06 503001-99 503999-99 82,83	
Biomedical							502005-05	
Wigwam							86	
Miscellaneous								
Pipelines				139				
Landfills								119
Prescribed Fires							89	
Forest Fires							87	
Structural Fires							88	
Respiration - Humans								142
- Animals								126,12 128, 1
Natural Soils								143,144, 146
Fertilized Soils								93
Anaesthetic Usage								140
Propellant Usage								141

TABLE 5.1.5 CO2 Emission Totals By Sector and Fuel Type (tonnes)

	Combustion								
Sector	Coal	Dist. Oil	Resid. Oil	Nat. Gas	Gasoline	Diesel	Other Fuels	Other Sources	Total
Industrial Process									
Cement Production								2,769,030	2,769,030
Lime Production								2,180,777	2,180,777
Coke Production								13,113,595	13,113,595
Ammonia Production								1,264,068	1,264,068
Pulp and Paper								3,026,311	3,026,311
								Total	**22,353,782**
Stationary Fuel Combustion									
Electric Power Generation	29,300,524	124,257		2,282					29,427,063
Industrial Fuel Combustion									
Point	4,821,146	18,070,108	14,196,515	7,195,801			5,994,410		50,277,980
Area	913,914	35,121	169,130	1,192,210			3,434		2,313,808
Commercial Fuel Combustion									
Point	16,595	281,609	268,721	965,306			9,586		1,541,818
Area		1,079,219	248,303	7,597,630			332,890		9,258,041
Residential Fuel Combustion									
Fuel Combustion		3,979,842	14,829	12,650,367			443,590		17,088,627
Fuel Wood							3,001,918		3,001,918
								Total	**112,909,255**
Transportation									
Automobiles					12,906,663	469,552			13,376,215
Light Duty Trucks					2,656,545	178,372			2,834,917
Medium Duty Trucks					2,242,882	505,840			2,748,722
Heavy Duty Trucks					253,525	3,663,756			3,917,280
Motorcycles					43,265				43,265
Highway - Line					7,619,840	1,451,398			9,071,238
Railroads						1,767,006			1,767,006
Marine			776,311			431,704			1,208,015
Aircraft							3,442,035		3,442,035
Off Road					622,891	2,251,219			2,874,110
								Total	**41,282,803**

TABLE 5.1.5 CO2 Emission Totals By Sector and Fuel Type (tonnes)

Sector	Combustion							Other Sources	Total
	Coal	Dist. Oil	Resid. Oil	Nat. Gas	Gasoline	Diesel	Other Fuels		
Incineration									
Municipal							677,961		677,961
Sewage Sludge							144,806		144,806
Industrial Waste							1,038,737		1,038,737
Biomedical							20,830		20,830
Wigwam							1,407,638		1,407,638
								Total	**3,289,972**
Miscellaneous									
Pipelines				2,048,785					2,048,785
Landfills								1,989,700	1,989,700
Prescribed Fires							132,754		132,754
Forest Fires							12,616,766		12,616,766
Structural Fires							214,520		214,520
Respiration - Humans								6,224,460	6,224,460
Respiration - Animals								15,814,394	15,814,394
								Total	**39,041,380**
TOTAL	35,052,179	23,570,155	15,673,808	31,652,382	26,345,611	10,718,847	29,481,874	46,382,336	218,877,193

TABLE 5.1.6 N2O Emission Totals By Sector and Fuel Type (Kg)

	Combustion								
Sector	Coal	Dist. Oil	Resid. Oil	Nat. Gas	Gasoline	Diesel	Other Fuels	Other Sources	Total
Industrial Process									
Coke Production								603,555	603,555
Nitric Acid Production								918,514	918,514
Pulp and Paper								277,844	277,844
Adipic Acid								11,400,000	11,400,000
								Total	13,199,913
Stationary Fuel Combustion									
Electric Power Generation	3,371,962	5,712		27					3,377,701
Industrial Fuel Combustion									
Point	208,708	830,663	597,651	83,761			246,364		1,967,146
Area	39,563	1,614	7,120	13,878			175		62,351
Commercial Fuel Combustion									
Point	718	12,945	11,313	11,236			1,489		37,702
Area		49,610	10,453	88,438			4,383		152,885
Residential Fuel Combustion									
Fuel Combustion		182,949	624	147,253			13,365		344,191
Fuel Wood							326,739		326,739
								Total	6,268,714
Transportation									
Automobiles					6,936,198	68,386			7,004,584
Light Duty Trucks					1,340,218	25,818			1,366,036
Medium Duty Trucks					1,152,251	73,217			1,225,468
Heavy Duty Trucks					26,784	527,855			554,639
Motorcycles					4,885				4,885
Highway - Line					4,300,135	87,758			4,387,893
Railroads						258,523			258,523
Marine			32,681			63,161			95,842
Aircraft							291,245		291,245
Off Road					58,165	329,366			387,531
								Total	15,576,647

5.2 Ontario Emissions by Contributing Sector

Detailed Emission Estimates

Total CO_2 and N_2O emissions are summarized, by SC/SCC code, in Table 5.1.3. Emissions of CO_2 are in tonnes; N_2O emissions are in kg. Sub-totals for area and point sources are also provided.

Emissions by Sector and Source Type

In order to interpret the data in Table 5.1.3, and to compare the emissions to other CO_2/N_2O inventories for Ontario, it is necessary to group the SC/SCC emissions into more descriptive categories. Table 5.1.4 documents the assignments of SCs and SCCs to sectors and source type (fuel combustion vs. other, and types of fuels) for use in interpreting the results. Tables 5.1.5 and 5.1.6 present CO_2 and N_2O emissions by sector/source type for each major fuel type, based on the assignments in Table 5.1.4.

Major contributors to the CO_2/N_2O emissions totals are as follows ((P) indicates point source, (A) indicates area source):

% Contribution	CO_2 Emissions	N_2O Emissions
≥10	Elec. Pow. Generation (P) Ind. Fuel Comb. (P)	Adipic Acid Prod. (P) Autos - Gas (A) Natural Soils (A)
5-10	Coke Prod. (P) Res. Fuel Comb. (A) Autos - Gas (A) Forest Fires (A) Resp. - Animals (A)	Highway Line (A) Electric Power Generation (P)
1-5	Cement Prod.(P) Lime Production (P) Pulp & Paper (P) Ind. Fuel Comb. (A) Comm. Fuel Comb. (A) Res. Wood Comb. (A) Light-Duty Trucks - Gas (A) Medium-Duty Trucks - Gas (A) Heavy-Duty Trucks - Gas (A) Highway Line (A) Aircraft (A) Off-road - Gas & Diesel (A) Resp. Humans (A)	Nitric Acid Prod. (P) Coke Production (P) Industrial Fuel Comb. (P) Light-Duty Trucks - Gas (A) Medium-Duty Trucks - Gas (A) Forest Fires (A) Fertilized Soils (A)

The utility and industrial fuel combustion (point) sectors were calculated to emit approximately 36% of the total CO_2 emitted in Ontario during the base year. The second grouping represented about 29% of the total emissions. Thus, these seven sectors accounted for about two-thirds of the total provincial CO_2 emission estimates in this inventory.

The largest sources of N_2O (adipic acid production, gasoline-powered automobiles and natural soils) were calculated to emit in the order of 62% of the total N_2O emission estimates for Ontario. Highway line sources (vehicular emissions, largely gasoline related) and utilities accounted for another 12%. Thus, five sectors were estimated to contribute three-quarters of the total inventoried N_2O emissions. However, the overall emissions and specific sector contributions of N_2O, which are regarded as preliminary (e.g., nitric acid processing and various types of fuel combustion and specific open sources), require confirmation.

Fuel Combustion Related Emissions

In examining combustion emissions by fuel type, CO_2 emissions from the primary fossil fuels (including: oil, coal, natural gas, as well as process gas).predominated contributions by other fuels such as: kerosene, NGL, propane, wood and waste. It should be noted that process gas consumption is included within the 'other' fuel category in the tabulations, and represented a significant but less certain contribution (see also Section 5.5). CO_2 emissions from coal are all inventoried as point sources in Ontario, with utilities predominating. Industrial point sources dominated CO_2 emissions from combustion of residual oil, distillate oil and other fuels. Forest fires, residential wood combustion and aircraft also accounted for a significant fraction of the CO_2 emissions from other fuels. Emissions of CO_2 from natural gas combustion are largely from the industrial point, commercial area, and residential (area) sectors. Of the various types of gasoline-powered vehicles, automobiles represented the largest source of CO_2 emissions, as might be expected. Diesel combustion related CO_2 emissions were predominantly from heavy-duty trucks, railroads and off-road diesel use.

N_2O emissions from fuel combustion were predominantly from gasoline combustion, with significant contributions from coal, distillate oil, diesel and wood combustion. Gasoline-related N_2O emissions were largely attributable to on-road gasoline-powered vehicles (autos, light and medium-duty trucks) that are included in both area and line sources. As for CO_2, utilities emitted most of coal combustion-related N_2O

TABLE 5.4.1b

SIC/Sector Assignments for the Fuel Combustion Point Source Report

Sector Description	SIC
Electric Power Generation	5720 Electric Utilities
Residential Fuel Comb.	9921 Apart. Gas-oil-coal
Residential Fuel Wood	(area source only)
Commercial Fuel Comb.	5060 Railway Transport 5170 Other Transport Services 5740 Gas Distribution 6420 Department Stores 7020 Savings Credit Inst. 7350 Insur.Real Est. Agencies 8310 Religious Organizations 8590 Other Recreat. Services 8690 Other Bus. Man. Services 8740 Laundries, Cleaner, Presser 8750 Hotels, Rest., Taverns 8990 Other Misc. Services
Federal Government	9020 Defence Services 9090 Other Federal Administ. 9910 Other Govt. Offices
Provincial Government	5790 Other Utilities
Municipal Government	5760 Water Systems 9510 Local Administration
Hospitals/Health	8210 Hospitals 8270 Other Health Services
Education	8010 Elementary & Sec. Schools 8050 Universities and Colleges 8090 Ed. & Related Services
Cement	3410 Cement Manufacturers

TABLE 5.4.1b (Contd.)

SIC/Sector Assignments for the Fuel Combustion Point Source Report

Sector Description	SIC
Mining, Milling	510 Placer Gold Mines
	520 Gold Quartz Mines
	560 Silver-Lead Zinc Mines
	580 Iron Mines
	590 Other Metal Mines
	730 Gypsum Mines
	770 Salt Mines
Smelting	2950 Smelting and Refining
Pulp and Paper	2710 Pulp & Paper Mills
Iron and Steel	2910 Iron & Steel Mills
	2920 Steel Pipe & Tube Mills
Iron Foundries	2940 Iron Foundries
Chemical	3690 Other Petro. & Coal Products
	3720 Mixed Fertilizers
	3730 Plastics, Synthetic Resins
	3740 Pharmaceuticals, Medicines
	3750 Paint & Varnish
	3760 Soap & Cleaning Compounds
	3780 Industrial Chemicals
	3790 Other Chemical Industries
	3850 Plastic Fabricators
	3990 Misc. Manufacturing Industries
Food and Beverages	190 Misc. Specialty Farms
	1010 Slaughter & Meat Processes
	1050 Dairy Factories
	1120 Fruit & Veg. Can//Preserv.
	1230 Feed Manufacturers
	1240 Flour Mills
	1250 Breakfast Cereal Man.

TABLE 5.4.1b (Contd.)

SIC/Sector Assignments for the Fuel Combustion Point Source Report

Sector Description	SIC
	1280 Biscuit Manufacturers 1290 Bakeries 1310 Confectionery Manuf. 1330 Sugar Refineries 1350 Vegetable Oil Mills 1390 Misc. Food Industries 1410 Soft Drink Industries 1430 Distilleries 1450 Breweries 1470 Wineries 1510 Leaf Tobacco Processing 1530 Tobacco Prod. Man.
Petroleum Refineries	3650 Petroleum Refineries 3651 Petroleum Storage
Other Non-Metallic Minerals	3450 Gypsum Prod. Manufacture 3470 Concrete Products 3510 Clay Products 3530 Stone Products 3540 Mineral Wood 3560 Glass and Glass Products 3570 Abrasives Manufacturers 3590 Other non-Metal Minerals
Auto Production	3230 Motor Vehicle Manufacture 3520 Motor Vehicle Parts, Acc.
Other Industrial	All Other SICs

TABLE 5.4.2 CO2 Fuel Combustion Emission Totals By Sector and Fuel Type (tonnes)

Sector	Coal	Oil	Nat. Gas	NGL	Other Fuels	Total Fuels
Electric Power Generation						
Electric Utilities	29,300,523	124,256	2,282			29,427,061
Residential						
Fuel Combustion Point Source		16,187				16,187
Fuel Combustion Area Sources		3,994,670	12,650,368	181,537	262,052	17,088,627
Fuel Wood Combustion					3,001,918	3,001,918
Commercial						
Point Sources		57,109	505,483			562,592
Area Sources		805,806	5,728,613	172,611	52,172	6,759,202
Government Institutional						
Point Sources						
Federal Government	10,156	40,184	28,388			78,728
Provincial Government			3,685			3,685
Municipal Government		12,104	2,822		9,199	24,125
Hospitals/Health		301,180	164,353	155	230	465,918
Education		63,096	91,379			154,475
Area Sources						
Federal Government		78,324	136,757	8,146	5,071	228,298
Provincial Government		61,066	106,367	6,420	3,954	177,807
Municipal Government		139,390	235,526	14,569	9,025	398,510
Hospitals/Health		53,101	303,905	9,878	3,438	370,322
Education		189,836	1,086,461	35,312	12,291	1,323,900
Industrial						
Point Sources						
Cement	4,088,677		2,498		52,344	4,143,519
Mining/Milling		42,737	156,925	2,538		202,200
Smelting		83,648	436,059	1,376	825	521,908
Pulp & Paper Mills	567,323	482,027	1,479,047		1,364,059	3,892,456
Iron & Steel Mills	2,693	118,197	473,351		528,278	1,122,519
Iron Foundries		6,507	8,670		160	15,337
Chemical		662,038	1,471,895	198	1,893,046	4,027,177
Food & Beverages		276,579	521,662	925	2,958	802,124
Petroleum Refineries		29,463,274	1,252,709	102,376	1,833,509	32,651,868
Other Non-Metallic Min.		11,943	378,253			390,196
Auto Production	160,481	571,767	56,133			788,381
Other Industrial	8,407	608,302	1,127,737	60,157	151,646	1,956,249
Sub-Total Industrial Point	**4,827,581**	**32,327,019**	**7,364,939**	**167,570**	**5,826,825**	**50,513,934**
Area Sources	913,914	204,251	1,192,210		3,434	2,313,809
TOTAL	35,052,174	38,467,579	29,603,538	596,198	9,189,609	112,909,098

TABLE 5.4.3 N2O Fuel Combustion Emission Totals by Sector and Fuel Type (kg)

Sector	Coal	Oil	Nat. Gas	Other Fuels	Total Fuels
Electric Power Generation					
Electric Utilities	3,371,962	5,711	26		3,377,699
Residential					
Fuel Combustion Point Source		681			681
Fuel Combustion Area Sources		183,573	147,253	13,365	344,191
Fuel Wood Combustion				326,739	326,739
Commercial					
Point Sources		2,404	5,881		8,285
Area Sources		36,458	66,682	2,660	105,800
Government Institutional					
Point Sources					
Federal Government	439	1,797	329		2,565
Provincial Government			42		42
Municipal Government		512	32	1,447	1,991
Hospitals/Health		13,435	1,911	40	15,386
Education		2,693	1,063		3,756
Area Sources					
Federal Government		3544	1592	259	5,395
Provincial Government		2763	1238	202	4,203
Municipal Government		6307	2742	460	9,509
Hospitals/Health		2403	3538	175	6,116
Education		8589	12647	627	21,863
Industrial					
Point Sources					
Cement	176,999		29	2,266	179,294
Mining/Milling		1,855	1,825		3,680
Smelting		3,639	5,075	35	8,749
Pulp & Paper Mills	24,559	21,255	17,216	148,468	211,498
Iron & Steel Mills	116	5,007	5,508	11,046	21,677
Iron Foundries		291	100	1	392
Chemical		29,025	17,128	34,016	80,169
Food & Beverages		12,387	6,066	525	18,978
Petroleum Refineries		1,304,277	14,580	31,386	1,350,243
Other Non-Metallic Min.		526	4,398		4,924
Auto Production	6,946	25,904	652		33,502
Other Industrial	363	26,815	13,109	18,612	58,899
Sub-Total Industrial Point	**208,983**	**1,430,981**	**85,686**	**246,355**	**1,972,005**
Area Sources	39,563	8,734	13,878	175	62,350
TOTAL	3,620,947	1,710,585	344,540	592,504	6,268,576

Specific assumptions were required in estimating office and other building space used by public service sectors.

Industrial stationary fuel combustion area sources were not broken down into further detail, because they emit a small amount of CO_2/N_2O relative to industrial stationary fuel combustion point sources.

The results of this analysis are provided in Tables 5.4.2 and 5.4.3 for CO_2 and N_2O, respectively. It should be noted that these apportionments are for stationary fuel combustion sources only, and exclude other specific contributions (e.g., incinerators, fuels consumed for transportation, etc.). The public administration sources considered accounted for approximately 3.2 million tonnes of CO_2 or ~2.8% of the Ontario total from stationary fuel combustion.

5.5 Comparison of Ontario Emission Inventory Estimates

Emissions of carbon dioxide have been estimated by the Ontario Ministry of Energy for fuel combustion sources in Ontario during 1988 (Ministry of Energy) and by Environment Canada with national totals and provincial contributions for the year 1987 (Environment Canada 1990). The present emission estimates for Ontario have been compared with these data, as shown in Table 5.5.1. In some instances, sector contributions have been rearranged from other reported tabulations, in order to provide consistency. It can be seen that comparisons between many of the sectors are generally favourable, while individual differences are generally attributable to factors such as: base quantity differences between years, estimated base quantities for some individual plants in the present study, fuel energy values selected and some differences in emission factors. In most cases, emission factors reported by Environment Canada were used in these compilations.

The overall total CO_2 emission estimate for the province differs rather significantly between the studies for the following reasons. The Ontario Ministry of Energy compilation includes fuel combustion sources only and, in some instances, base quantities for the year were based on forecasts of fuel consumption. The compilation does not include the fraction of CO_2 generated by industrial processing (e.g., cement and lime calcination, etc.) and excludes the open sources. Similarly,

TABLE 5.5.1

Comparison of Ontario CO_2 Emission Inventory Data (10^6 Tonnes CO_2)

Sector	Min. of Energy (1988)	Environment Canada (1987)	MOE/ORTECH (1987/88)
Industrial			
Cement Production	-	2.21	2.77
Ammonia Production	-	0.97	1.26
Pulp & Paper - SSL Comb.	7.10[a]	5.68	2.61
- Lime Kilns	-	-	0.42
Coke Production	15.42	-[b]	13.11
Lime Production	-	-	2.18
Sub-total	22.52	8.86	22.35
Stationary Fuel Combustion			
Electric Power Generation	32.31	30.29	29.43
Industrial Fuel Comb.	34.37[c]	36.18	52.59[d]
Commercial Fuel Comb.	10.86	8.26[e]	10.80
Residential Fuel Comb.	17.45	15.82	17.09
Fuelwood Comb.	1.55	2.88	3.00
Agricultural Fuel Comb.	1.55	0.67	-
Sub-total	98.09	94.10	112.91
Transportation			
Gasoline Vehicles	28.74	28.22	25.73[f]
Diesel Vehicles	7.76[g]	10.00[g]	6.27[f]
Railroads	1.07[h]	1.26	1.77
Marine		0.97	1.21
Aircraft	4.21	3.90	3.45
Off-Road Gasoline	-	0.66	0.62
Off-Road Diesel	-	-	2.25
Natural Gas	0.64	1.74	-
Propane	-	0.59	-
Sub-total	42.42	47.34	41.30

TABLE 5.5.1 (contd.)

Comparison of Ontario CO_2 Emission Inventory Data
(10^6 Tonnes CO_2)

Sector	Min. of Energy (1988)	Environment Canada (1987)	MOE/ORTECH (1987/88)
Incineration			
Municipal Incineration	-	0.24[i]	0.68
Sewage Sludge Incin.	-		0.14
Industrial Incin.	-	0.17[j]	1.04
Commercial Incin.	-		0.02
Wigwam Burners	-	0.82	1.41
Sub-total	-	1.23	3.29
Open Sources			
Pipelines	2.07	-	2.05
Prescribed Fires	-	2.63	0.13
Structural Fires	-	-	0.21
Forest Fires	-	-	12.62
Landfills	-	-	1.99
Animal Respiration (Domestic)	-	-	15.81
Human Respiration	-	-	6.22
Sub-total	2.07	2.63	39.03
Overall Totals:	**165.10**	**154.16**	**218.88**

Notes

- source contribution not available

a. Includes woodwaste combusted in boilers, MOE/ORTECH data includes woodwaste contributions in the industrial fuel combustion sector.

b. Coke contribution presumably included in the industrial fuel combustion sector.

c. Includes petroleum refinery combustion sources.

d. Point source contributions = 50.28×10^6 Tonnes CO_2 and includes in-process fuel combustion emissions.

e. Includes 0.63×10^6 Tonnes CO_2 attributable to public administration combustion.

f. Includes area and line source contributions, but excludes off-road fuel contributions.

g. Includes contribution from diesel vehicles and off-road diesel engines.

h. Includes both railroad and marine contribution.

i. Includes both municipal and sewage sludge incinerators.

j. Includes both industrial and commercial incinerators.

open sources (including specific natural sources) were not addressed in the Environment Canada anthropogenic inventory. Thus, some additional sources have been included in the present study which accounted for a substantial fraction of the total emissions. On the other hand, some presently minor sources (e.g., natural gas and propane vehicle fuel contributions) are not included in the MOE database. The other significant difference relates to the industrial fuel combustion contribution which was substantially higher in the present study. This resulted from differences in inventory methods used, and the treatment of in-process fuels. For example, in most instances, the former compilations have used published Statistics Canada fuel combustion data to define the total industrial fuel base quantities with assignments on an area source basis. It is uncertain whether or not coal consumption, used for coking in the iron and steel sectors, have been included in the Environment Canada total emissions for Ontario. In the present study, fuel combustion data for individual plants have been compiled in MOE point source files which were used to estimate emissions for each plant and combined for this sector. The point source fuel consumption data are normally deducted by MOE from the published fuel statistics, with the balance assigned to area source files. On the basis of the present compilation, the point source contribution represented most of the combined point and area source total (~96%) of industrial fuel combustion (see Table 5.1.5). In addition, the contribution by internally generated in-process fuels by some industries (e.g., petroleum refineries, carbon black production, etc.) have been included in this sector. In process COG combustion at iron and steel production facilities was deleted since associated emissions were accounted for in the coke production sector. Due to the complexity in properly assigning in-process gas contributions, it is possible that a small portion of the emissions for this overall industrial fuel combustion sector have been double-counted. However, specific efforts were made to properly assess and account for the various industrial fuels used. Hence, a more in-depth examination of such contributions appear to be required, in order to define overall differences in emissions for the industrial fuel combustion sector between the studies. Apart from the discrepancy for this one sector, generally favourable agreement was found for most of the sectors that are directly comparable, despite some differences in inventory techniques. As other inventories of N_2O have not yet been compiled in detail. Ontario emissions of this gas could not be compared, and the associated emission quantities compiled in this study should be regarded as preliminary estimates only.

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